INSTITUTION

OF

MECHANICAL ENGINEERS.

ESTABLISHED 1847.

PROCEEDINGS.

1894.

PARTS 1–2.

PUBLISHED BY THE INSTITUTION,
19 VICTORIA STREET, WESTMINSTER, S.W.

CONTENTS.

1894.

PARTS 1–2.

PAST-PRESIDENTS.

George Stephenson, 1847-48. (*Deceased* 1848.)

Robert Stephenson, F.R.S., 1849-53. (*Deceased* 1859.)

Sir William Fairbairn, Bart., LL.D., F.R.S., 1854-55. (*Deceased* 1874.)

Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., 1856-57, 1866. (*Deceased* 1887.)

John Penn, F.R.S., 1858-59, 1867-68. (*Deceased* 1878.)

James Kennedy, 1860. (*Deceased* 1886.)

The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., 1861-62, 1869.

Robert Napier, 1863-65. (*Deceased* 1876.)

John Ramsbottom, 1870-71.

Sir William Siemens, D.C.L., LL.D., F.R.S., 1872-73. (*Deceased* 1883.)

Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S., 1874-75.

Thomas Hawksley, F.R.S., 1876-77. (*Deceased* 1893.)

John Robinson, 1878-79.

Edward A. Cowper, 1880-81. (*Deceased* 1893.)

Percy G. B. Westmacott, 1882-83.

Sir Lowthian Bell, Bart., F.R.S., 1884.

Jeremiah Head, 1885-86.

Sir Edward H. Carbutt, Bart., 1887-88.

Charles Cochrane, 1889.

Joseph Tomlinson, 1890-91. (*Deceased* 1894.)

William Anderson, D.C.L., F.R.S., 1892-93.

Institution of Mechanical Engineers.

OFFICERS.

1894.

PRESIDENT.

Alexander B. W. Kennedy, LL.D., F.R.S., ... London.

PAST-PRESIDENTS.

William Anderson, D.C.L., F.R.S., ... Woolwich.
The Rt. Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., Newcastle-on-Tyne.
Sir Lowthian Bell, Bart., F.R.S., ... Northallerton.
Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S., London.
Sir Edward H. Carbutt, Bart., ... London.
Charles Cochrane, ... Stourbridge.
Jeremiah Head, ... London.
John Ramsbottom, ... Alderley Edge.
John Robinson, ... Leek.
Percy G. B. Westmacott, ... Newcastle-on-Tyne.

VICE-PRESIDENTS.

Sir James N. Douglass, F.R.S., ... London.
Sir Douglas Galton, K.C.B., D.C.L., F.R.S., ... London.
Edward B. Marten, ... Stourbridge.
Edward P. Martin, ... Dowlais.
Sir James Ramsden, ... Barrow-in-Furness.
E. Windsor Richards, ... Low Moor.

MEMBERS OF COUNCIL.

John A. F. Aspinall, ... Horwich.
William Dean, ... Swindon.
Benjamin A. Dobson, ... Bolton.
John Hopkinson, Jun., D.Sc., F.R.S., ... London.
Samuel W. Johnson, ... Derby.
Arthur Keen, ... Birmingham.
William Laird, ... Birkenhead.
John G. Mair-Rumley, ... London.
Francis C. Marshall, ... Newcastle-on-Tyne.
Henry D. Marshall, ... Gainsborough.
Edward P. Martin, ... Dowlais.
William H. Maw, ... London.
James Platt, ... Gloucester.
T. Hurry Riches, ... Cardiff.
William H. White, C.B., LL.D., F.R.S., ... London.
J. Hartley Wicksteed, ... Leeds.

TREASURER.

Harry Lee Millar.

SECRETARY.

Alfred Bache,

Institution of Mechanical Engineers, 19 Victoria Street, Westminster, S.W.

[Telegraphic address:—*Mech, London.* Telephone, 3264.]

THE INSTITUTION OF MECHANICAL ENGINEERS.

Memorandum of Association.

AUGUST 1878.

1st. The name of the Association is "THE INSTITUTION OF MECHANICAL ENGINEERS."

2nd. The Registered Office of the Association will be situate in England.

3rd. The objects for which the Association is established are :—

(A.) To promote the science and practice of Mechanical Engineering and all branches of mechanical construction, and to give an impulse to inventions likely to be useful to the Members of the Institution and to the community at large.

(B.) To enable Mechanical Engineers to meet and to correspond, and to facilitate the interchange of ideas respecting improvements in the various branches of mechanical science, and the publication and communication of information on such subjects.

(C.) To acquire and dispose of property for the purposes aforesaid.

(D.) To do all other things incidental or conducive to the attainment of the above objects or any of them.

4th. The income and property of the Association, from whatever source derived, shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly, by way of dividend, bonus, or otherwise howsoever, by way of profit to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them: Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any Member of the Association, or other person, in return for any services rendered to the Association, or prevent the giving of privileges to the Members of the Association in attending the meetings of the Association, or prevent the borrowing of money (under such powers as the Association and the Council thereof may possess) from any Member of the Association, at a rate of interest not greater than five per cent. per annum.

5th. The fourth paragraph of this Memorandum is a condition on which a licence is granted by the Board of Trade to the Association in pursuance of Section 23 of the Companies Act 1867. For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which shall be duly observed by the Association.

6th. If the Association act in contravention of the fourth paragraph of this Memorandum, or of any such further conditions, the liability of every Member of the Council shall be unlimited; and the liability of every Member of the Association who has received any such dividend, bonus, or other profit as aforesaid, shall likewise be unlimited.

7th. Every Member of the Association undertakes to contribute to the Assets of the Association in the event of the same being wound up during the time that he is a Member, or within one

year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a Member, and of the costs, charges, and expenses for winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding Five Shillings, or in case of his liability becoming unlimited such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

8th. If upon the winding up or dissolution of the Association there remains, after the satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the Members of the Association, but shall be given or transferred to some other Institution or Institutions having objects similar to the objects of the Association, to be determined by the Members of the Association at or before the time of dissolution; or in default thereof, by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter.

Articles of Association.

FEBRUARY 1893.

INTRODUCTION.

Whereas an Association called "The Institution of Mechanical Engineers" existed from 1847 to 1878 for objects similar to the objects expressed in the Memorandum of Association of the Association (hereinafter called "the Institution") to which these Articles apply;

And whereas the Institution was formed in 1878 for furthering and extending the objects of the former Institution, by a registered Association, under the Companies Acts 1862 and 1867;

And whereas terms used in these Articles are intended to have the same respective meanings as they have when used in those Acts, and words implying the singular number are intended to include the plural number, and *vice versâ*;

NOW THEREFORE IT IS HEREBY AGREED as follows :—

CONSTITUTION.

1. For the purpose of registration the number of members of the Institution is unlimited.

MEMBERS, ASSOCIATE MEMBERS, GRADUATES, ASSOCIATES, AND HONORARY LIFE MEMBERS.

2. The present Members of the Institution, and such other persons as shall be admitted in accordance with these Articles, and none others, shall be Members of the Institution, and be entered on the register as such.

3. Any person may become a Member of the Institution who shall be qualified and elected as hereinafter mentioned, and shall agree to become such Member, and shall pay the entrance fee and first subscription accordingly.

4. The qualification of Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

5. The election of Members shall be conducted as prescribed by the By-laws from time to time in force, as provided by the Articles.

6. In addition to the persons already admitted as Graduates, Associates, and Honorary Life Members respectively, the Institution may admit such persons as may be qualified and elected in that behalf as Associate Members, Graduates, Associates, and Honorary Life Members respectively of the Institution, and may confer upon them such privileges as shall be prescribed by the By-laws from time to time in force, as provided by the Articles: provided that no Associate Member, Graduate, Associate, or Honorary Life Member shall be deemed to be a Member within the meaning of the Articles.

7. The qualification and mode of election of Associate Members, Graduates, Associates, and Honorary Life Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

8. The rights and privileges of every Member, Associate Member, Graduate, Associate, or Honorary Life Member shall be personal to himself, and shall not be transferable or transmissible by his own act or by operation of law.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. The Entrance Fees and Subscriptions of Members, Associate Members, Graduates, and Associates shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

EXPULSION.

10. If any Member, Associate Member, Graduate, or Associate shall leave his subscription in arrear for two years, and shall fail to pay such arrears within three months after a written application has been sent to him by the Secretary, his name may be struck off the register by the Council at any time afterwards, and he shall thereupon cease to have any rights as a Member, Associate Member, Graduate, or Associate, but he shall nevertheless continue liable to pay the arrears of subscription due at the time of his name being so struck off: provided always that this regulation shall not be construed to compel the Council to remove any name, if they shall be satisfied the same ought to be retained.

11. The Council may refuse to continue to receive the subscriptions of any person who shall have wilfully acted in contravention of the regulations of the Institution, or who shall in the opinion of the Council have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution; and may remove his name from the register, and he shall thereupon cease to be a Member, Associate Member, Graduate, or Associate (as the case may be) of the Institution.

GENERAL MEETINGS.

12. The General Meetings shall consist of the Ordinary Meetings, the Annual General Meeting, and of Special Meetings as hereinafter defined.

13. The Annual General Meeting shall take place in London in one of the first four months of every year. The Ordinary Meetings shall take place at such times and places as the Council shall determine.

14. A Special Meeting may be convened at any time by the Council, and shall be convened by them whenever a requisition signed by twenty Members or Associate Members of the Institution,

specifying the object of the Meeting, is left with the Secretary. If for fourteen days after the delivery of such requisition a Meeting be not convened in accordance therewith, the Requisitionists or any twenty Members or Associate Members of the Institution may convene a Special Meeting in accordance with the requisition. All Special Meetings shall be held in London.

15. Seven clear days' notice of every Meeting, specifying generally the nature of any special business to be transacted at any Meeting, shall be given to every person on the register of the Institution, except as provided by Article 35, and no other special business shall be transacted at such Meeting; but the non-receipt of such notice shall not invalidate the proceedings of such Meeting. No notice of the business to be transacted (other than such ballot lists as may be requisite in case of elections) shall be required in the absence of special business.

16. Special business shall include all business for transaction at a Special Meeting, and all business for transaction at every other Meeting, with the exception of the reading and confirmation of the Minutes of the previous Meeting, the election of Members, Associate Members, Graduates, and Associates, and the reading and discussion of communications as prescribed by the By-laws, or by any regulations of the Council made in accordance with the By-laws.

PROCEEDINGS AT GENERAL MEETINGS.

17. Twenty Members or Associate Members shall constitute a quorum for the purpose of a Meeting other than a Special Meeting. Thirty Members or Associate Members shall constitute a quorum for the purpose of a Special Meeting.

18. If within thirty minutes after the time fixed for holding the Meeting a quorum is not present, the Meeting shall be dissolved, and all matters which might, if a quorum had been present, have been done at a Meeting (other than a Special Meeting) so dissolved, may forthwith be done on behalf of the Meeting by the Council.

19. The President shall be Chairman at every Meeting, and in his absence one of the Vice-Presidents; and in the absence of all Vice-Presidents a Member of Council shall take the chair; and if no Member of Council be present and willing to take the chair, the Meeting shall elect a Chairman.

20. The decision of a General Meeting shall be ascertained by show of hands, unless, after the show of hands, a poll is forthwith demanded; and by a poll, when a poll is thus demanded. The manner of taking a show of hands or a poll shall be in the discretion of the Chairman; and an entry in the Minutes, signed by the Chairman, shall be sufficient evidence of the decision of the General Meeting. Each Member and Associate Member shall have one vote and no more. In case of equality of votes the Chairman shall have a second or casting vote: provided that this Article shall not interfere with the provisions of the By-laws as to election by ballot.

21. The acceptance or rejection of votes by the Chairman shall be conclusive for the purpose of the decision of the matter in respect of which the votes are tendered: provided that the Chairman may review his decision at the same Meeting, if any error be then pointed out to him.

BY-LAWS.

22. The By-laws set forth in the schedule to these Articles, and such altered and additional By-laws as shall be substituted or added as hereinafter mentioned, shall regulate all matters by the Articles left to be prescribed by the By-laws, and all matters which consistently with the Articles shall be made the subject of By-laws. Alterations in, and additions to, the By-laws, may be made only by resolution of the Members and Associate Members at an Annual General Meeting, after notice of the proposed alteration or addition has been announced at the previous Ordinary Meeting, and not otherwise.

COUNCIL.

23. The Council of the Institution shall be chosen from the Members only, and shall consist of one President, six Vice-Presidents, fifteen ordinary Members of Council, and of the Past-Presidents. The President, two Vice-Presidents, and five Members of Council (other than Past-Presidents), shall retire at each Annual General Meeting, but shall be eligible for re-election. The Vice-Presidents and Members of Council to retire each year shall, unless the Council agree among themselves, be chosen from those who have been longest in office, and in cases of equal seniority shall be determined by ballot.

24. The election of a President, Vice-Presidents, and Members of Council, to supply the place of those retiring at the Annual General Meeting, shall be conducted in such manner as shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

25. The Council may supply any casual vacancy in the Council (including any casual vacancy in the office of President) which shall occur between one Annual General Meeting and another; and the President, Vice-Presidents, or Members of Council so appointed by the Council shall retire at the succeeding Annual General Meeting. Vacancies not filled up at any such Meeting shall be deemed to be casual vacancies within the meaning of this Article.

OFFICERS.

26. The Treasurer, Secretary, and other employés of the Institution shall be appointed and removed in the manner prescribed by the By-laws from time to time in force, as provided by the Articles. Subject to the express provisions of the By-laws, the officers and servants of the Institution shall be appointed and removed by the Council.

27. The powers and duties of the officers of the Institution shall, subject to any express provision in the By-laws, be determined by the Council.

POWERS AND PROCEDURE OF COUNCIL.

28. The Council may regulate their own procedure, and delegate any of their powers and discretions to any one or more of their body, and may determine their own quorum: if no other number is prescribed, three members of Council shall form a quorum.

29. The Council shall manage the property, proceedings, and affairs of the Institution, in accordance with the By-laws from time to time in force.

30. The Treasurer may, with the consent of the Council, invest in the name of the Institution any moneys not immediately required for the purposes of the Institution in or upon any of the following investments (that is to say):—

(A) The Public Funds, or Government Stocks of the United Kingdom, or of any Foreign or Colonial Government guaranteed by the Government of the United Kingdom.

(B) Real or Leasehold Securities, or in the purchase of real or leasehold properties in Great Britain or Ireland.

(C) Debentures, Debenture Stock, or Guaranteed or Preference Stock, of any Company incorporated by special Act of Parliament, the ordinary Shareholders whereof shall at the time of such investment be in actual receipt of half-yearly or yearly dividends.

(D) Stocks, Shares, Debentures, or Debenture Stock of any Railway, Canal, or other Company, the undertaking whereof is leased to any Railway Company at a fixed or fixed minimum rent.

(E) Stocks, Shares, or Debentures of any East Indian Railway or other Company, which shall receive a contribution from Her Majesty's East Indian Government of a fixed annual percentage on their capital, or be guaranteed a fixed annual dividend by the same Government.

(F) The security of rates levied by any corporate body empowered to borrow money on the security of rates, where such borrowing has been duly authorised by Act of Parliament.

31. The Council may, with the authority of a resolution of the Members and Associate Members in General Meeting, borrow moneys for the purposes of the Institution on the security of the property of the Institution, or otherwise at their discretion.

32. No act done by the Council, whether *ultra vires* or not, which shall receive the express or implied sanction of the Members and Associate Members in General Meeting, shall be afterwards impeached by any member of the Institution on any ground whatsoever, but shall be deemed to be an act of the Institution.

NOTICES.

33. A notice may be served by the Council upon any Member, Associate Member, Graduate, Associate, or Honorary Life Member, either personally or by sending it through the post in a prepaid letter addressed to him at his registered place of abode.

34. Any notice, if served by post, shall be deemed to have been served at the time when the letter containing the same would be delivered in the ordinary course of the post; and in proving such service it shall be sufficient to prove that the letter containing the notice was properly addressed and put into the post office.

35. No Member, Associate Member, Graduate, Associate, or Honorary Life Member, not having a registered address within the United Kingdom, shall be entitled to any notice; and all proceedings may be had and taken without notice to such member, in the same manner as if he had had due notice.

By-laws.

(Last Revision, February 1894.)

MEMBERSHIP.

1. Candidates for admission as Members must be persons not under twenty-five years of age, who, having occupied during a sufficient period a responsible position in connection with the practice or science of Engineering, may be considered by the Council to be qualified for election.

2. Candidates for admission as Associate Members must be persons not under twenty-five years of age, who, being engaged in such work as is connected with the practice or science of Engineering, may be considered by the Council to be qualified for election, though not yet to occupy positions of sufficient responsibility, or otherwise not yet to be eligible, for admission as Members. They may afterwards be transferred at the discretion of the Council to the class of Members.

3. Candidates for admission as Graduates must be persons holding subordinate situations, and not under eighteen years of age. They must furnish evidence of training in the principles as well as in the practice of Engineering. Before attaining the age of twenty-six years, those elected after 1892 must apply for election as Members, Associate Members, or Associates, if they desire to remain connected with the Institution; they may not continue Graduates after attaining the age of twenty-six.

4. Candidates for admission as Associates must be persons not under twenty-five years of age, who from their scientific attainments or position in society may be considered eligible by the Council. They may afterwards be transferred at the discretion of the Council to the class of Associate Members or of Members.

5. The Council shall have the power to nominate as Honorary Life Members persons of eminent scientific acquirements, who in their opinion are eligible for that position.

6. The Members, Associate Members, Graduates, Associates, and Honorary Life Members shall have notice of and the privilege to attend all Meetings; but Members and Associate Members only shall be entitled to vote thereat.

7. The abbreviated distinctive Titles for indicating the connection with the Institution of Members, Associate Members, Graduates, Associates, or Honorary Life Members thereof, shall be the following:—for Members, M. I. Mech. E.; for Associate Members, A. M. I. Mech. E.; for Graduates, G. I. Mech. E.; for Associates, A. I. Mech. E.; for Honorary Life Members, Hon. M. I. Mech. E.

8. Subject to such regulations as the Council may from time to time prescribe, any Member, Associate Member, or Associate may upon application to the Secretary obtain a Certificate of his membership or other connection with the Institution. Every such certificate shall remain the property of, and shall on demand be returned to, the Institution.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. Each Member shall pay an Annual Subscription of £3, and on election an Entrance Fee of £2.

10. Each Associate Member shall pay an Annual Subscription of £2 10*s*., and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Members, he shall pay on transference 10*s*. additional subscription for the current year, and £1 additional entrance fee.

11. Each Graduate shall pay an Annual Subscription of £1 10*s*., but no Entrance Fee. Any Graduate elected prior to 1893, if transferred by the Council to the class of Associate Members, shall pay on transference £1 additional subscription for the current year, but no additional entrance fee; if transferred direct to the class of Members, he shall pay on transference £1 10*s*. additional subscription for the current year, and £1 additional entrance fee.

12. Each Associate shall pay an Annual Subscription of £2 10*s*., and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Associate Members, he shall pay on transference no additional subscription or entrance fee. If transferred direct to the class of Members, he shall pay on transference 10*s*. additional subscription for the current year, and £1 additional entrance fee; except Associates elected prior to 1893, who shall pay no additional entrance fee on transference.

13. All subscriptions shall be payable in advance, and shall become due on the 1st day of January in each year; and the first subscription of Members, Associate Members, Graduates, and Associates, shall date from the 1st day of January in the year of their election.

14. In the case of Members, Associate Members, Graduates, or Associates, elected in the last three months of any year, the first subscription shall cover both the year of election and the succeeding year.

15. Any Member, Associate Member, or Associate, whose subscription is not in arrear, may at any time compound for his subscription for the current and all future years by the payment of Fifty Pounds, if paid in any one of the first five years of his membership. If paid subsequently, the sum of Fifty Pounds shall be reduced by One Pound per annum for every year of membership after five years. All compositions shall be deemed to be capital moneys of the Institution.

16. The Council may at their discretion reduce or remit the annual subscription, or the arrears of annual subscription, of any Member or Associate Member who shall have been a subscribing member of the Institution for twenty years, and shall have become unable to continue the annual subscription provided by these By-laws.

17. No Proceedings or Ballot Lists or Certificates shall be sent to Members, Associate Members, Graduates, or Associates, who are in

arrear with their subscriptions more than twelve months, and whose subscriptions have not been remitted by the Council as hereinbefore provided.

ELECTION OF MEMBERS, ASSOCIATE MEMBERS, GRADUATES, AND ASSOCIATES.

18. A recommendation for admission according to Form A or B in the Appendix shall be forwarded to the Secretary, and by him be laid before the next Meeting of the Council. The recommendation must be signed by not less than five Members or Associate Members if the application be for admission as a Member or Associate Member or Associate, and by three Members or Associate Members if it be for a Graduate.

19. All elections shall take place by ballot, four-fifths of the votes given being necessary for election.

20. All applications for admission shall be communicated by the Secretary to the Council for their approval previous to being inserted in the ballot list for election, and the approved ballot list shall be signed by the President and forwarded to the Members and Associate Members. The name of any Candidate approved by the Council for admission as an Associate Member or an Associate shall not be inserted in the ballot list until he has signed the Form C in the Appendix. The ballot list shall specify the name, occupation, and address of the Candidates, and also by whom proposed and seconded. The lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

21. The Elections shall take place at the General Meetings only.

22. When the proposed Candidate is elected, the Secretary shall give him notice thereof according to Form D; but his name shall not be added to the register of the Institution until he shall have paid his Entrance Fee and first Annual Subscription, and signed the Form E in the Appendix.

23. In case of non-election, no mention thereof shall be made in the Minutes, nor any notice given to the unsuccessful Candidate.

24. An Associate Member desirous of being transferred to the class of Members, or an Associate to the class of Associate Members or of Members, shall forward to the Secretary a recommendation according to Form F in the Appendix, signed by not less than five Members or Associate Members, which shall be laid before the next meeting of Council for their approval. On their approval being given, the Secretary shall notify the same to the Candidate according to Form G; but his name shall not be added to the list of Members or Associate Members until he shall have signed the Form H, and shall have paid the additional entrance fee (if any), and the additional subscription (if any) for the current year.

ELECTION OF PRESIDENT, VICE-PRESIDENTS, AND MEMBERS OF COUNCIL.

25. Candidates shall be put in nomination at the General Meeting preceding the Annual General Meeting, when the Council are to present a list of their retiring Members who offer themselves for re-election; any Member or Associate Member shall then be entitled to add to the list of Candidates. The ballot list of the proposed names shall be forwarded to the Members and Associate Members. The ballot lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

APPOINTMENT AND DUTIES OF OFFICERS.

26. The Treasurer shall be a Banker, and shall hold the uninvested funds of the Institution, except the moneys in the hands of the Secretary for current expenses. He shall be appointed by the Members and Associate Members at a General or Special Meeting, and shall hold office at the pleasure of the Council.

27. The Secretary of the Institution shall be appointed, as and when a vacancy occurs, by the Members and Associate Members at a General or Special Meeting, and shall be removable by the Council upon six months' notice from any day. The Secretary shall give the same notice. The Secretary shall devote the whole of his time to the work of the Institution, and shall not engage in any other business or profession.

28. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all meetings of the Institution, and of the Council, and of Committees; to take minutes of the proceedings of such meetings; to read the minutes of the preceding meetings, and all communications that he may be ordered to read; to superintend the publication of such papers as the Council may direct; to have the charge of the library; to direct the collection of the subscriptions, and the preparation of the account of expenditure of the funds; and to present all accounts to the Council for inspection and approval. He shall also engage (subject to the approval of the Council) and be responsible for all persons employed under him, and set them their portions of work and duties. He shall conduct the ordinary business of the Institution, in accordance with the Articles and By-laws and the directions of the President and Council; and shall refer to the President in any matters of difficulty or importance, requiring immediate decision.

MISCELLANEOUS.

29. All Papers shall be submitted to the Council for approval, and after their approval shall be read by the Secretary at the General Meetings, or by the Author with the consent of the Council; or, if so directed by the Council, shall be printed in the Proceedings without having been read at a General Meeting.

30. All books, drawings, communications, &c., shall be accessible to the members of the Institution at all reasonable times.

31. All communications to the Meetings shall be the property of the Institution, and be published only by the authority of the Council.

32. None of the property of the Institution—books, drawings, &c.—shall be taken out of the premises of the Institution without the consent of the Council.

33. All donations to the Institution shall be enumerated in the Annual Report of the Council presented to the Annual General Meeting.

34. The General Meetings shall be conducted as far as practicable in the following order:—

1st. The Chair to be taken at such hour as the Council may direct from time to time.

2nd. The Minutes of the previous Meeting to be read by the Secretary, and, after being approved as correct, to be signed by the Chairman.

3rd. The Ballot Lists, previously opened by the Council, to be presented to the Meeting, and the new Members, Associate Members, Graduates, and Associates elected to be announced.

4th. Papers approved by the Council to be read by the Secretary, or by the Author with the consent of the Council.

35. Each Member or Associate Member shall have the privilege of introducing one friend to any of the Meetings; but, during such portion of any meeting as may be devoted to any business connected with the management of the Institution, visitors shall be requested by the Chairman to withdraw, if any Member or Associate Member asks that this shall be done.

36. Every Member, Associate Member, Graduate, Associate, or Visitor, shall write his name and residence in a book to be kept for the purpose, on entering each Meeting.

37. The President shall ex officio be member of all Committees of Council.

38. Seven clear days' notice at least shall be given of every meeting of the Council. Such notice shall specify generally the business to be transacted by the meeting. No business involving the expenditure of the funds of the Institution (except by way of payment of current salaries and accounts) shall be transacted at any Council meeting unless specified in the notice convening the meeting.

39. The Council shall present the yearly accounts to the Annual General Meeting, after being audited by a professional accountant, who shall be appointed annually by the Members and Associate Members at a General or a Special Meeting, at a remuneration to be then fixed by the Members and Associate Members.

40. Any member wishing to have a copy of the Papers sent to him for consideration beforehand can do so by sending in his name once in each year to the Secretary; and a copy of all Papers shall then be forwarded to him as early as possible prior to the date of the Meeting at which they are intended to be read.

41. At any Meeting of the Institution any member shall be at liberty to re-open the discussion upon any Paper which has been read or discussed at the preceding Meeting; provided that he signifies his intention to the Secretary at least one month previously to the Meeting, and that the Council decide to include it in the notice of the Meeting as part of the business to be transacted.

APPENDIX.

FORM A.

Mr. being years of age, and desirous of admission into the Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our personal knowledge, and the three other signers from trustworthy information, propose and recommend him as a proper person to belong to the Institution.

Witness our hands, this day of

Members or Associate Members.

FORM B.

Mr. born on being desirous of admission into the Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our personal knowledge, and the other signer or signers from trustworthy information, propose and recommend him as a proper person to become a Graduate thereof.

Witness our hands, this day of

Members or Associate Members.

FORM C.

If elected an of the Institution of Mechanical Engineers, I, the undersigned, do hereby engage to ratify my election by signing the form of agreement and paying the entrance fee and annual subscription in conformity with the By-laws.

Witness my hand, this day of

FORM D.

Sir,—I have to inform you that on the you were elected a of the Institution of Mechanical Engineers. For the ratification of your election in conformity with the rules, it is requisite that the enclosed form be returned to me with your signature, and that your Entrance Fee and first Annual Subscription be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the election will become void.

I am, Sir, Your obedient servant,

Secretary.

FORM E.

I, the undersigned, being elected a of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they are now formed or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

FORM F.

Mr. being years of age, and desirous of being transferred into the class of of the Institution of Mechanical Engineers, we, the undersigned, from our personal knowledge recommend him as a proper person to be so transferred by the Council.

Witness our hands, this day of

Members or Associate Members.

FORM G.

Sir,—I have to inform you that the Council have approved of your being transferred to the class of of the Institution of Mechanical Engineers. For the ratification of your transference in conformity with the rules, it is requisite that the enclosed form be returned to me with your signature, and that your additional Entrance Fee and additional Annual Subscription for the current year be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the transference will become void.

I am, Sir, Your obedient servant,

Secretary.

FORM H.

I, the undersigned, having been transferred to the class of of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they now exist, or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

Institution of Mechanical Engineers.

PROCEEDINGS.

February 1894.

The Forty-Seventh Annual General Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Thursday, 1st February 1894, at Half-past Seven o'clock p.m.; Dr. William Anderson, F.R.S., Retiring President, in the chair, succeeded by Professor Alexander B. W. Kennedy, F.R.S., President elected at the Meeting.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following twenty-four candidates were found to be duly elected:—

MEMBERS.

Brindley, George Samuel, . .	Birmingham.
Cottrill, John Ormerod, . .	Bolton.
Haigh, Noel Newall, . . .	Oldham.
Harrison, William John, . .	Brazil.
Hopkinson, Edward, D.Sc., . .	Manchester.
Humpidge, James Dickerson, . .	Dudbridge.
Irwin, Thomas F., . . .	Liverpool.
Mackie, John, ...	Reading.
Mather, George Radford, . .	Wellingborough.
Pearce, Robert McLardy, . .	Jamalpur.
Riley, Joseph Hacking, . .	Bury, Lancs.

TURNER, ALBERT, ...	Manchester.
WEBB, HENRY, ...	Bury, Lancs.
WORSDELL, WILSON, . . .	Gateshead.

ASSOCIATE MEMBERS.

GRAHAM, MAURICE, . . .	London.
KERSLAKE, WALTER EDMUND, . .	Liverpool.
McGEORGE, JAMES, . . .	Rangoon.
ROSSITER, JAMES THOMAS, . .	London.
STONE, SIDNEY, ...	London.
THORPE, WALTER CHARLES, . .	Nottingham.

GRADUATES.

BARBER, EDWARD WHITLEY, . .	Manchester.
HALSEY, CHARLES TURNER, . .	London.
JOHNSON, WALTER WROE, . .	Leeds.
PETTER, PERCIVAL WADDAMS, . .	Yeovil.

The following Annual Report of the Council was then read:—

ANNUAL REPORT OF THE COUNCIL.

1894.

This is the Forty-Seventh Annual General Meeting of the Institution; and the Annual Report which the Council have the pleasure of presenting to the Members respecting the proceedings of the Institution during the past year is as follows.

At the end of last year the number of names in all classes on the roll of the Institution was 2,157, as compared with 2,147 at the end of the previous year, showing a net gain of 10. During 1893 there were added to the register 106 names; against which the loss by decease was 31, and by resignation or removal 65.

During the past year a baronetcy has been conferred upon Sir Frederick A. Abel, K.C.B., Honorary Life Member of the Institution.

The following nine Transferences have been made by the Council in 1893:—

To the class of Members.

Burnet, Lindsay,	Graduate	Glasgow.
Dugard, William Henry,	do.	Birmingham.
Malan, Ernest de Mérindol,	do.	Hull.
Ripley, Philip Edward,	do.	Ipswich.
Treharne, Gwilym Alexander,	do.	Aberdare.

To the class of Associate Members.

Day, Arthur Godfrey,	Associate	Bath.
Barker, Eric Gordon,	Graduate	Birkenhead.
Bromly, Alfred Hammond,	do.	Llanuwchllyn.
Crosland, Delevante William,	do.	London.

The following thirty-two Deceases of Members of the Institution have occurred during the past year:—

ADAMSON, THOMAS ALFRED,	London.
ALLEN, ALFRED EVANS,	Hull.
BORNS, GEORG MAXIMILIAN,	Masterton, N.Z.
BREEDEN, JOSEPH,	Birmingham.
BROTHERHOOD, ARTHUR MAUDSLAY,	London.
CARRICK, SAMUEL STEWART,	London.
CARVER, HENRY CLIFTON,	Manchester.
COLQUHOUN, JAMES,	Weston-super-Mare.
COWPER, EDWARD ALFRED,	London.
CROSS, ROBERT JAMES,	Bristol.
DAVIS, JOSEPH,	Manchester.
DÜBS, HENRY JOHN SILLARS,	Glasgow.
ELLIOT, SIR GEORGE, Bart.,	Houghton-le-Spring.
FENTON, JAMES,	London.
FOSTER, FREDERICK,	London.
HAWKSLEY, THOMAS, F.R.S.,	London.
HOLT, FRANCIS,	Derby.
HOMER, CHARLES JAMES,	Stoke-upon-Trent.
KEELING, HERBERT HOWARD,	Eltham.
LAIRD, HENRY HYNDMAN,	Birkenhead.
LONGSDON, ALFRED (Associate),	London.
MACNEE, DANIEL,	London.
NETTLEFOLD, HUGH,	Birmingham.
NORTH, GEORGE,	London.
RODGER, WILLIAM,	Bombay.
SINCLAIR, ROBERT COOPER,	London.
STRINGER, WILLIAM,	Manchester.
TILFOURD, GEORGE (Associate, deceased 1892),	Sheffield.
TURNER, GEORGE REYNOLDS,	Nottingham.
WALKER, RALPH TEASDALE (Graduate),	Java.
WARSOP, HENRY,	Nottingham.
WRIGHT, JOSEPH,	Westminster.

Of these Mr. Cowper had been a Member of the Institution and a Member of Council from the commencement in 1847, and occupied the Presidential chair in the years 1880 and 1881. Mr. Hawksley, who died at the advanced age of eighty-six, had been a Member of the Institution from 1856, and President in 1876 and 1877 Mr. Laird had been a Member of Council from 1877 to 1879.

The following thirty-five gentlemen have ceased to be Members of the Institution during the past year:—

BAILEY, CHARLES STUART,	North Carolina, U.S.
BENNETTS, EDWARD JOHN,	Krugersdorp.
BOULTBEE, FREDERIC RICHARD,	London.
BRADLEY, ISAAC,	Birmingham.
BRICKNELL, AUGUSTUS LEA,	London.
BROWN, FREDERICK GILLS,	London.
CHUBB, EDWARD GEORGE (Associate),	Ironbridge.
CHUBB, THOMAS LYON,	Buenos Aires.
CLARKE, FRANCIS,	Canterbury.
CROSSLEY, WILLIAM,	Glasgow.
EMETT, GEORGE HENRY HAWKINS,	Dewsbury.
ENGLAND, WILLIAM HENRY (Graduate),	Leeds.
HARKER, HAROLD HAYES,	Rio de Janeiro.
HEADLY, LAWRANCE,	Cambridge.
KNOX, JAMES,	Auckland, N.Z.
LEE, CHARLES EYRE,	Birmingham.
LINDSAY, JOSEPH,	Dundee.
LIVESEY, JOSEPH MONTAGUE (Associate),	Horncastle.
MAY, HAROLD MILTON (Graduate),	Totnes.
MCLEAN, WILLIAM LECKIE EWING,	Renfrew.
MONK, EDWIN,	London.
NICOLSON, DONALD,	London.
O'FLYN, JOHN LUCIUS,	Cardiff.
PUDAN, OLIVER,	Johnstown, U.S.
REEVES, FRANK,	Buenos Aires.
RICHES, CHARLES HURRY,	Cardiff.
RICHES, GLENFORD MITCHELL,	Grimsby.
ROBINS, EDWARD,	London.
SCOTT, ROBERT,	London.
SMITH, HENRY BUCKLEY BINGHAM (Graduate),	Glasgow.
TEMPLETON, EDWIN ARTHUR SLADE (Graduate),	London.
WHITTLE, JOHN,	Chorley.
WOODFORD, ETHELBERT GEORGE,	Port Beira.
WYNNE-EDWARDS, THOMAS ALURED,	Denbigh.
YATES, EDWARD (Graduate),	Stony Stratford.

In addition to these there have been thirty Resignations of membership.

The Accounts for the year ending 31 December 1893 are now submitted to the Members (*see* pages 10–13), after having been passed by the Finance Committee, and certified by Mr. Robert A. McLean, chartered accountant, the auditor appointed by the Members at the last Annual General Meeting. The receipts during the year were £7,030 11*s.* 4*d.*, while the expenditure, actual and estimated, was £5,257 12*s.* 8*d.*, leaving a balance of receipts over expenditure of £1,772 18*s.* 8*d.* The financial position of the Institution at the end of the year is shown by the balance sheet: the total investments and other assets amount to £35,913 18*s.* 11*d.*; and allowing £600 for accounts owing but not yet rendered, the capital of the Institution amounts to £35,313 18*s.* 11*d.*, of which the greater part, as seen from the balance sheet, is invested in Railway Debenture Stocks, registered in the name of the Institution. The certificates of the whole of the securities have been duly audited by the Finance Committee and the auditor.

With a view to relieving the Finance Committee from a considerable amount of routine work, which has hitherto taxed somewhat heavily their time and convenience, while pertaining more properly to the auditor's duties, the Council have now arranged that in future the audit shall be half-yearly instead of yearly. In this connection they have also taken into consideration the fact that the amount of work involved in the existing annual audit has largely increased since it was originally undertaken by the present auditor sixteen years ago, the number of members being now nearly double what it was then. Under these circumstances the Council recommend that the previous remuneration of ten guineas be increased to twenty-five guineas, agreeably with the notice already circulated for the annual appointment of auditor, to be made by the Members at the present meeting in accordance with By-law 39.

In view of the increasing number of those who have been Members of the Institution for a lengthened period, the Council have had under their further consideration during the past year the subject of Compounding for Life Membership. As the result of their enquiries and deliberations they have decided to propose at the present meeting an alteration of the existing By-law, in accordance

with the notice already given to this effect, whereby the amount of the composition will continually diminish as the duration of membership becomes longer.

The Alloys Research Committee, of which the President is the chairman, received from Professor Roberts-Austen his second report, which was read and discussed at the Spring Meeting. A large portion of the report was devoted to Copper, and the discussion was the means of eliciting much valuable information from those who have had long practical experience in the working of this metal.

The Research Committee on the Value of the Steam-Jacket, since the presentation of their second report in October 1892, have been continuing their experiments during the past year under the chairmanship of Mr. Henry Davey; and the results obtained are in progress of being worked out with a view to the preparation of a third report as soon as the materials available have been put into suitable shape.

The series of Marine-Engine Trials carried out by the Research Committee under the chairmanship of Professor Kennedy have been summarised and reviewed by Professor Beare, whose paper dealing with them in this manner is announced for reading and discussion at the present meeting.

The Library of the Institution has received by presentation and exchange during the past year the additions enumerated in pages 14–22, for which the Council here record their thanks to the several Donors. Members who have published works valuable for reference, or original pamphlets on engineering subjects, or records of experiments, of which they could present copies, are reminded that such contributions to the Library are acceptable for permanent preservation.

The General Meetings in 1893 were the Annual General Meeting and the Spring Meeting, both held in London; the Summer Meeting in Middlesbrough; and the Autumn Meeting in London. Altogether

eight sittings were occupied in the reading and discussion of ten of the following Papers, which are published in the Proceedings:—

Description of the Experimental Apparatus and Shaping Machine for Ship Models at the Admiralty Experiment Works, Haslar; by Mr. R. Edmund Froude.

Description of the Pumping Engines and Water-Softening Machinery at the Southampton Water Works; by Mr. William Matthews.

Second Report to the Alloys Research Committee; by Professor W. C. Roberts-Austen, C.B., F.R.S.

Tensile Tests and Chemical Analyses of Copper Plates from Fire-boxes of Locomotives on the Great Western Railway; by Mr. William Dean.

Experiments on the Draught produced in different parts of a Locomotive Boiler when running; by Mr. John A. F. Aspinall.

On recent developments in the Cleveland Iron and Steel Industries; by Mr. Jeremiah Head, Past-President.

On the Middlesbrough Salt Industry; by Mr. Richard Grigg.

Description of the Electric Rock-Drilling Machinery at the Carlin How Ironstone Mines in Cleveland; by Mr. A. L. Steavenson.

On some Engineering Improvements in the River Tees; by Mr. George J. Clarke.

The Port and Industries of the Hartlepools; by Mr. Thomas Mudd.

On the Artificial Lighting of Workshops; by Mr. Benjamin A. Dobson.

On the Working of Steam Pumps on the Russian South Western Railways; by Mr. Alexander Borodin.

Experiments on Heat Losses from Dry and Wet Cylinder Walls exposed to a Vacuum, &c.; by Mr. Bryan Donkin.

The attendances during 1893 were as follows:—at the Annual General Meeting 103 Members and 35 Visitors; at the Spring Meeting 68 Members and 53 Visitors; at the Summer Meeting 174 Members and 123 Visitors; and at the Autumn Meeting 81 Members and 54 Visitors.

The Summer Meeting was held for the second time in Middlesbrough, after an interval of twenty-two years since the previous visit in 1871. A review of the developments which have taken place during that period in the leading industries of the Cleveland district formed the subject of an elaborate paper prepared for the occasion by Mr. Jeremiah Head, Past-President, giving rise

to valuable discussion upon some of the numerous matters of interest dealt with therein, and enabling the Members more fully to appreciate the opportunities afforded them of visiting the blast-furnaces, iron and steel works, and other engineering establishments opened to their inspection. To Mr. Head also, as Chairman of the Reception Committee, with the assistance of his son Mr. Archibald P. Head, and of Mr. John Dennington as Honorary Secretary, were due the obliging arrangements for the convenience and enjoyment of the Members; while through the kindness of the Mayor, Charles Lowthian Bell, Esq., the Town Hall was placed at the disposal of the Institution for the Meeting and for all purposes connected therewith. Visits to the Port Clarence Salt Works, the Ironstone Mines, the South Gare Breakwater, and the Tees Estuary, were rendered all the more interesting by the descriptions given of these works in papers contributed by Mr. Richard Grigg, Mr. A. L. Steavenson, and Mr. George J. Clarke. An excursion was also made to Thornaby for visiting the principal engineering and other works there situated.

A visit to Hartlepool, arranged by the kindness of Mr. Thomas Mudd as Honorary Secretary, afforded a welcome opportunity on the concluding day of the Meeting for realising the rapid growth of the port and industries of the Hartlepools, the interest of which was enhanced by a succinct description prepared for the occasion by Mr. Mudd. This excursion was made by steamers from Stockton and Middlesbrough on the invitation of the Tees Conservancy Commissioners; and the Members were indebted to the invitation of the Directors of the North Eastern Railway for the trains placed at their disposal throughout the preceding days of the Meeting.

In accordance with the Rules of the Institution, the President, two Vice-Presidents, and five Members of Council, retire from office this day. The result of the ballot for the election of the Council for the present year will be announced to the Meeting.

Dr. ACCOUNT OF EXPENDITURE AND RECEIPTS

Expenditure.	£ s. d.	£ s. d.
To Printing and Engraving Proceedings of 1893 .	960 12 3	
Less Authors' Copies of Papers, repaid	2 2 0	958 10 3
„ Stationery and General Printing		199 5 3
„ Binding		73 9 2
„ Rent		710 0 0
„ Salaries and Wages		2,043 16 0
„ Coal, Firewood, and Lighting		34 2 6
„ Fittings and Repairs		147 5 1
„ Postages, Telegrams, and Telephone		266 15 1
„ Insurance		7 0 6
„ Petty Expenses		32 3 1
„ Meeting Expenses—		
Printing	167 12 10	
Reporting	48 13 6	
Diagrams, Screen, &c.	42 5 0	
Travelling and Incidental Expenses	132 5 7	390 16 11
„ Dinner Guests		153 8 0
„ Research		224 15 4
„ Books purchased		16 5 6
		5,257 12 8
Accounts owing, not yet rendered, say	600 0 0	
Less Reserve in previous year for accounts since paid	600 0 0	0 0 0
Balance, being excess of Receipts over Expenditure, carried down		1,772 18 8
		£7,030 11 4

To Investment—		
£2,272 14*s.* *India 3% Stock*	2,250 0 0	
Less Balance from conversion of L. & N.W. Ry. Stock	0 6 8	2,249 13 4
Cash Balance 31st December 1893		2,487 18 11
		£4,737 12 3

FOR THE YEAR ENDING 31ST DECEMBER 1893. *Cr.*

Receipts.				£	s.	d.	£	s.	d.
By Entrance Fees—									
53 *New Members at £2*				106	0	0			
35 *New Associate Members at £1*				35	0	0			
4 *New Associates at £1*				4	0	0			
5 *Graduates transferred to Members at £1*				5	0	0	150	0	0
„ Subscriptions for 1893—									
1656 *Members at £3*				4,968	0	0			
35 *Associate Members at £2 10s.*				87	10	0			
66 *Associates at £2 10s.*				165	0	0			
132 *Graduates at £1 10s.*	198	0	0						
5 *Graduates rebate at 10s.*	2	10	0	195	10	0			
5 *Graduates transferred to Members at £1 10s.*				7	10	0			
3 *Graduates transferred to Associate Members at £1*				3	0	0	5,426	10	0
„ Subscriptions in arrear—									
69 *Members at £3*				207	0	0			
1 *Associate at £3*				3	0	0			
8 *Graduates at £2*				16	0	0	226	0	0
„ Subscriptions in advance—									
28 *Members at £3*				84	0	0			
2 *Graduates at £1 10s.*				3	0	0	87	0	0
„ Interest—									
From Investments				804	0	3			
From Whitworth Bequest				234	1	0			
From Bank				39	17	1	1,077	18	4
„ Reports of Proceedings—									
Extra Copies sold							63	3	0
							£7,030	11	4

	£	s.	d.
By Balance brought down	1,772	18	8
Cash Balance 31st December 1892	2,964	13	7
	£4,737	12	3

Dr. BALANCE SHEET

	£ s. d.
To Sundry Creditors—	
Accounts owing, not yet rendered, say	600 0 0
Capital of the Institution at this date . . . . (exclusive of back numbers of Proceedings, which cost £4,690)	35,313 18 11
	£35,913 18 11

Signed by the following members of the Finance Committee:—

WILLIAM ANDERSON,
DOUGLAS GALTON,
ALEX. B. W. KENNEDY,
WILLIAM H. MAW.

AS AT 31ST DECEMBER 1893. *Cr.*

			£ s. d.
		£ s. d.	
By Cash—*In Union Bank, on Deposit*		1,600 0 0	
" " " *on Current account* . .		387 18 11	
In London Joint Stock Bank	474 19 6		
In hand	25 0 6	500 0 0	2,487 18 11
" Investments—(*cost* £24,786 16*s*. 3*d*.)			
£ 2,200 *North Eastern Ry.*	4% *Debenture Stock*		
1,800 *Great Western* "	" " "		
2,244 *Great Eastern* "	" " "		
2,755 *Metropolitan* "	" " "		
2,325 " "	3½% " "		
1,000 *Aire and Calder Navigation*	" " "		
*4,237 *London and North Western Ry.*	3% " "		
3,288 *Midland Railway*	" " "		
2,450 *Taff Vale* "	" " "		
2,272 14*s*. *India Stock*	" " "		
700 *Sir J. Whitworth and Co., Ld.*	5% " "		
Two hundred £10 shares Sir J. Whitworth and Co., Ld.			
The Market Value of these investments at 31st Dec. 1893 was about . .			31,523 0 0
" Subscriptions in Arrear, probable value			220 0 0
" Office Furniture and Fittings			343 0 0
" Library			1,240 0 0
" Drawings, Engravings, Models, Specimens, and Sculpture .			100 0 0
" Proceedings, back numbers at cost £4,690			
			£35,913 18 11

* Converted from previous £3,178 of 4% Debenture Stock.

Audited and Certified by

ROBERT A. McLEAN, Chartered Accountant,
1 Queen Victoria Street, London, E.C.

LIST OF DONATIONS TO LIBRARY.

Construction of the Great Victoria Bridge in Canada, by James Hodges; from Mr. J. Lyons Sampson.

Dynamo Machinery, by Dr. John Hopkinson; from the author.

Theory of Structures and Strength of Materials, by Professor Henry T. Bovey; from the author.

The Steam Engine, by D. K. Clark; from the author.

Practical Surveying, by G. W. Usill; from Messrs. Crosby, Lockwood and Son.

Handbook on the Steam Engine, by H. Haeder and H. H. P. Powles; from Messrs. Crosby, Lockwood and Son.

The Worthington Pumping Engine; from Messrs. Simpson and Co.

Duty and Capacity Tests of Worthington High-duty Pumping Engines; from the Worthington Pumping Engine Co.

Personal Recollections of Werner von Siemens; from Mr. Alexander Siemens.

Memoir of Timothy Hackworth; from Mr. Robert Young.

Portative Electricity, by J. T. Niblett; from the author.

Popular Electric Lighting, by Captain E. Ironside Bax; from the author.

Diamonds and Gold in South Africa, by Theodore Reunert; from the author.

Marine Boiler Management and Construction, by C. E. Stromeyer; from the author.

Students' Cotton Spinning (2nd ed. 1893), by Joseph Nasmith; from the author.

Molesworth's Pocket-Book of Engineering Formulæ, 1893; from the authors.

Illustrated Official Handbook of the Cape and South Africa; from Messrs. W. Clowes and Sons.

Annual Reports of the Chief of the Bureau of Steam Engineering, United States Navy Department, 1892 and 1893; from the Bureau.

Presidential Address to the Junior Engineering Society, 1892, by Dr. John Hopkinson; from the author.

Researches on the Dry Concentration of the Sulphides of the Barrier Range, New South Wales, by Thomas Clarkson; from the author.

Report on Permanent Bridge of Boats across the River Ravi in the Punjab (Indian P.W.D. Serial No. 28); Completion Report of the Nagpur Water Works High Level Extension, 1890 (Indian P.W.D. Serial No. 29); from the India Office.

Classified Lists and Distribution Returns of Establishment, Indian Public Works Department, to 31 Dec. 1892 and 30 June 1893; from the Registrar.

The following from Mons. E. Sauvage :—Accélération des pièces à mouvement alternatif des Machines à Vapeur; Écoulement de l'Eau des Chaudières; Note sur le service des Mécaniciens et Chauffeurs en Angleterre; Pertes de charge dans les Conduites d'Eau d'après la formule de M. Flamant; Système Anglais des Signaux de chemins de fer; Exploitation de l'Anthracite en Pennsylvanie.

Future of British Engineering, by C. S. Du Riche Preller; from the author.

Réponse à la brochure de M. Julius Von Schutz, Directeur au Grüsonwerk, sur les Coupoles et Cuirasses allemandes et la contrefaçon française; from Mr. Henry Chapman.

Étude sur les pertes de charge de l'Air Comprimé et de la Vapeur dans les tuyaux de conduite, by Charles Ledoux; from the author.

Rapport de la Commission chargée de l'essai de la Locomotive à grande vitesse, système Compound-Tandem, des Chemins de fer Sud-Ouest Russes, by Alexander Borodin; from the author.

Cornell University, exercises at the opening of the Library Building; from Sibley College.

Affaire de Panama: Plaidoirie de Me. Waldeck-Rousseau pour M. Eiffel; l'Arrêt de la Cour de Paris du 9 Février 1893, en ce qui concerne M. Eiffel; from M. Eiffel.

Rede zum Geburtsfeste seiner Majestät des Kaisers und Königs Wilhelm II in der Aula der Königlichen Technischen Hochschule zu Berlin, 26 Januar 1893; from the Rector.

Adumbration of Inventions, by G. G. M. Hardingham; from the author.

Second Report on the development of Graphic Methods in Mechanical Science, by Professor H. S. Hele-Shaw; from the author.

Presidential Address to the Society of Engineers, 1893, by W. A. Valon; from the author.

List of Chinese Lighthouses, Light Vessels, Buoys, and Beacons, 1893; from the Inspector-General of Chinese Customs.

De la Vergne System of Refrigerating and Ice-Making Machinery; from Mr. L. Sterne.

Development of the Machinery of Atlantic Liners, by A. J. Maginnis; from the author.

Petroleum in Eastern Europe, and the method of drilling for it, by A. W. Eastlake; from the author.

Duty Trial of Pumping Engine; from the Blake Manufacturing Co.

Report to London County Council on the Flow of the Thames, by A. R. Binnie; from the author.

Catalogue of the Sanitary Appliances at the Museum of the Hornsey Local Board, Highgate; from Mr. T. de Courcy Meade.

Condensed treatise on the Law of Patents, by W. E. Simonds; from the author.

Report to the Governors of the City and Guilds of London Institute, April 1893; from the Institute.

Alloys of Iron and Chromium, by R. A. Hadfield; from the author.

Report of Trials of Pumping Engines at the new Sewage Pumping Station, Leicester; from Messrs. Gimson and Co.

Report to the Council of the Neapolitan Steam Boiler Association, by Francesco Sinigaglia; from the Association.

Report of the Kew Observatory Committee, 1892; from the Committee.

Modern Travelling Crane, by A. E. Outerbridge, Jun.; from Messrs. William Sellers and Co.

Clyde Navigation: description of new Dredging Plant; description of 130-ton Crane Seat and Steam Crane on Finnieston Quay, Glasgow Harbour; from Mr. James Deas.

Register of the Institute of Chemistry of Great Britain and Ireland, 1893; from the Institute.

Proposed High-level Roadway Bridge across the River Mersey at Liverpool; from Mr. John J. Webster.

Comparisons between the different systems of distributing Electricity, by Professor Henry Robinson; from the author.

Present development of Heavy Ordnance in the United States, by Lieut. W. H. Jaques; from the author.

Du Rôle et de l'Efficacité des Enveloppes de Vapeur dans les machines compound, by A. Witz; from the author.

Friction of Lubricated Bearings, by J. Hartley Wicksteed; from the author.

Comparative Tests of Hellesen and Electrical Construction Co.'s Dry Battery Cells, by Professor A. Jamieson; from the author.

The following from the Ordnance Office, Washington, United States:—Annual Report of the United States Chief of Ordnance, 1892; Notes on the Construction of Ordnance; Tests of Metals &c. at Watertown Arsenal, Massachusetts, 1891 and 1892; Report of the Board of Officers to select Magazine Arms for the United States Military Service.

Thermal Storage: reports and press notices, and reports by William Schönheyder; from Mr. Druitt Halpin.

Report of Sewer Commissioners, Canton, Ohio; from Mr. L. E. Chapin.

Lightning Express Railway Service, by F. B. Behr; from the author.

Possible and Impossible Economies in the Utilisation of Energy, by Professor Alexander B. W. Kennedy; from the author.

Calendar of Sibpur Civil Engineering College, India, 1893; from the College.

Drilling apparatus for Water and Gas Mains, by H. W. Pearson; from the author.

Das Hängen der Gichten in den Hochöfen; from Mr. Charles Cochrane.

Die Verbrennung im Gestell des Hochofens; from Mr. Charles Cochrane.

Massachusetts Institute of Technology, Boston, its foundation, character, and equipment; from the Institute.

Report of the Hydraulic Engineer on the Water Supply of Queensland; from Mr. J. B. Henderson.

Metal Industries of Russia, by Professor N. Labzin; from the author.

The following official publications from the Government of New South Wales:—
Annual statement of works carried out by Public Works Department, 1891; Fifth Annual Report of the Metropolitan Board of Water Supply and Sewerage, 1892; Report on Utilisation of the River Darling; Wealth and Progress of New South Wales, 1892, by T. A. Coghlan.

Presidential Address to the Mechanical Science Section of the British Association, 1893, by Jeremiah Head; from the author.

Manufacture and Testing of Portland Cement, by Henry Faija; from the author.

Warming and Ventilation, by Frank Ashwell; from the author.

Formal Opening of the Engineering and Physics Buildings, McGill University; from Professor Henry T. Bovey.

Some aspects of Lubrication, by J. Veitch Wilson; from Price's Candle Co.

Official Catalogue of the British Section, Chicago Exhibition, 1893; from the Royal Commission.

Handbooks of Commercial Products, Indian Section, Iron (No. 8) and Indian Coal (No. 9); from the Imperial Institute.

Notes on the Progress of Lighthouses, by David A. Stevenson; from the author.

Report on Trials of the City Gas Engine, by R. B. Hodgson and Benjamin Young; from Mr. R. B. Hodgson.

Considérations sur le Régulateur de Watt &c., by N. J. Raffard; from the author.

Minutes of Proceedings of the International Maritime Congress, London, 1893; from the Congress.

First Steam Screw-Propeller Boats to Navigate the waters of any country, by F. B. Stevens; from the author.

Bradford Corporation Electricity Supply, 1890-93, by J. N. Shoolbred; from the author.

Interdependence of Abstract Science and Engineering (James Forrest Lecture 1893), by Dr. William Anderson; from the Institution of Civil Engineers.

Calcul de l'Épaisseur des Chaudières à Vapeur, by Francesco Sinigaglia; from the author.

Iron Alloys with special reference to Manganese Steel, by R. A. Hadfield; from the author.

Board of Trade Reports on Boiler Explosions; from the Board of Trade.

Annual Report of the City Engineer, Newton, Massachusetts, 1892; from Mr. Henry Chapman.

Contract Trial of the U.S.S. "New York," by E. R. Freeman and M. A. Anderson ; from Mr. Henry Chapman.

Calendars for 1893–94 from the following Colleges:—Royal Technical High School, Berlin; Mason Science College, Birmingham ; University College, Bristol; Yorkshire College, Leeds; City of London College; King's College, London; Firth College, Sheffield.

Gas Engineer's Pocket Almanack, 1893 ; from Messrs. William Sugg and Co.

Lockwood's Builder's and Contractor's price-book, 1893 ; from Messrs. Crosby, Lockwood and Son.

Advertiser's A. B. C. of official scales and Advertisement Press Directory, 1893 ; from Mr. T. B. Browne.

Griffin's Electrical Engineer's price-book ; from the publishers.

Spons' Engineers' and Contractors' Diary and Reference Book, 1894 ; from the publishers.

Illustrated catalogue of Steel and Iron Wire Ropes; from Messrs. George Cradock and Co.

Three catalogues of Electric Lamps, Fittings, and Instruments; from Messrs. Edison and Swan.

Illustrated price-list of Wrought-Iron Pulleys, Shafting, and Friction Couplings ; from Messrs. J. Bagshaw and Sons.

Catalogue of Testing Machines and Appliances; from the Riehlé Testing Machine Co.

Catalogue of Mathematical Instruments ; from Mr. W. F. Stanley.

Catalogue of Iron and Wire Fencing ; from Messrs. David Rowell and Co.

Ironmonger Diary, 1894 ; from the publishers.

From the United States Geological Survey.

Eleventh Annual Report (two parts) of the United States Geological Survey, 1889–90, by J. W. Powell.

Mineral Resources of the United States, 1891.

Bulletins of the United States Geological Survey, Nos. 82–86 and 90–96.

The following three Monographs of the Survey :—

XVII. The Flora of the Dakota Group, by Leo Lesquereux.

XVIII. Gasteropoda and Cephalopoda of the Raritan Clays and Greensand Marls of New Jersey, by Robert Parr Whitfield.

XX. Geology of the Eureka District, Nevada (with Atlas), by Arnold Hague.

From the Patent Office.

The following Abridgments of Specifications of Patents for Inventions, 1877–83:—Classes 3–8, 10, 11, 13, 16, 18, 19, 21, 23–27, 29–34, 42, 44–52, 54, 55, 57, 58, 62, 64–71, 73–81, 84–89, 91, 93–97, 99–111, 113–118, 120–124, 126–135, 137–140, 142–146.

The following Publications from the respective Societies and Authorities:—

Reports of the Academy of Science, France.
Engravings from the École des Ponts et Chaussées, Paris.
Annales des Ponts et Chaussées, Paris.
Proceedings of the French Institution of Civil Engineers.
Journal of the French Society for the Encouragement of National Industry.
Annales des Mines.
Annales du Conservatoire des Arts et Métiers.
Journal of the Marseilles Scientific and Industrial Society.
Proceedings of the Industrial Society of St. Quentin et de l'Aisne.
Proceedings of the Industrial Society of the North of France.
Proceedings of the Industrial Society of Rouen.
Proceedings of the Industrial Society of Mulhouse.
Annals of the Association of Engineers of Ghent.
Proceedings of the Society of German Engineers.
Reports of the Royal Academy of Science, Belgium.
Reports of the Royal Institute of Engineers, Holland.
Proceedings of the Engineers' and Architects' Society of Canton Vaud.
Proceedings of the Engineers' and Architects' Society of Austria.
Proceedings of the Engineers' and Architects' Society of Prague.
Proceedings of the Architects' and Engineers' Society of Hannover.
Proceedings of the Italian Engineers' and Architects' Society.
Proceedings of the Russian Imperial Institute of Engineers.
Proceedings of the Swedish Technical Society.
Journal of the Norwegian Technical Society.
Journal of the Franklin Institute.
Transactions of the American Society of Civil Engineers.
Transactions of the American Institute of Mining Engineers.
School of Mines Quarterly, Columbia College, New York.
Report of the Smithsonian Institution.
Report of the Master Car-Builders' Association, New York.
Proceedings of the United States Naval Institute.
United States Patent Office Gazette.
Journal of the Association of Engineering Societies.

Journal of the United States Artillery.
Transactions of the Canadian Society of Civil Engineers.
Proceedings and Journal of the Asiatic Society of Bengal.
Proceedings of the Committee of Locomotive and Carriage Superintendents for India.
Proceedings of the Engineering Association of New South Wales.
Proceedings of the Institution of Civil Engineers.
Journal of the Iron and Steel Institute.
Transactions of the Society of Engineers.
Journal of the Institution of Electrical Engineers.
Transactions of the Civil and Mechanical Engineers' Society.
Transactions of the North of England Institute of Mining and Mechanical Engineers.
Proceedings of the South Wales Institute of Engineers.
Transactions of the Institution of Engineers and Shipbuilders in Scotland.
Transactions of the Chesterfield and Midland Counties Institution of Engineers.
Transactions of the Liverpool Engineering Society.
Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers.
Proceedings of the Cleveland Institution of Engineers.
Transactions of the Mining Institute of Scotland.
Transactions of the North-East Coast Institution of Engineers and Shipbuilders.
Transactions of the Hull and District Institution of Engineers and Naval Architects.
Proceedings of the South Staffordshire Institute of Iron and Steel Works Managers.
Proceedings of the Royal Society of London.
Proceedings of the Royal Society of Edinburgh.
Proceedings of the Royal Institution of Great Britain.
Transactions and Professional Notes of the Surveyors' Institution.
Journal of the Royal United Service Institution.
Professional Papers of the Royal Engineers' Institute.
Journal of the Royal Agricultural Society of England.
Journal of the Royal Statistical Society.
Report of the British Association for the Advancement of Science.
Report of the Royal Cornwall Polytechnic Society.
Transactions of the Institution of Naval Architects.
Transactions and Journal of the Royal Institute of British Architects.
Transactions of the Incorporated Gas Institute.
Proceedings of the Physical Society of London.
Proceedings of the Literary and Philosophical Society of Manchester.
Transactions of the Manchester Geological Society.
Journal of the Royal Scottish Society of Arts.
Proceedings of the Philosophical Society of Glasgow.

Transactions and Proceedings of the Royal Irish Academy.
Transactions and Proceedings of the Royal Dublin Society.
Transactions of the Institute of Marine Engineers.
Journal of the Liverpool Polytechnic Society.
Journal of the Society of Arts.
Journal of the Society of Chemical Industry.
Journal of the Society of Architects.
Transactions of the Manchester Association of Engineers.
Transactions of the Junior Engineering Society.
Reports of the Manchester Steam Users' Association; from Mr. Lavington E. Fletcher.
Report of the National Boiler and General Insurance Company; from Mr. Edward G. Hiller.
Report of the Engine, Boiler, and Employers' Liability Insurance Company: from Mr. Michael Longridge.
Report of the London Association of Foremen Engineers and Draughtsmen.
Twenty-third Annual Report of the Bradford Free Public Libraries.
Fortieth Annual Report of the Liverpool Free Public Library.
Forty-first Annual Report of the Manchester Public Free Libraries.
Catalogue of Additions to the Radcliffe Library, Oxford, during 1892.

The following Periodicals from the respective Editors:—

Revue générale des Chemins de fer.
Revue universelle des Mines.
Revue industrielle.
Stahl und Eisen.
Der Civil-Ingenieur.
Glaser's Annalen.
Giornale del Genio Civile.
Ingeniero y Ferretero Español y Sud Americano.
The Engineering and Mining Journal.
The National Car and Locomotive Builder.
The American Engineer and Railroad Journal.
The Railway Master Mechanic.
The Indian Engineer.
The Engineer.
Engineering.
The Railway Engineer.
The Marine Engineer.
Iron.
The Iron and Coal Trades Review.
Ryland's Iron Trade Circular.
The Ironmonger.
Ironmongery.
The Textile Recorder.
The Mechanical World.
The Mining Journal.
The Colliery Guardian.
The Machinery Market.
The Builder.
The Electrical Review.
The Chamber of Commerce Journal (from Mr. Henry Chapman).
The Contract Journal.
The Plumber and Decorator.

The Shipping World.
The Steamship.
The Fireman.
Industries.
Invention.
The Practical Engineer.
Electrical Plant.
Hardware Trade Journal.
The Railway Review.
Phillips' Monthly Machinery Register.
The Engineering Review.
Canadian Mining Review.
Cassier's Magazine.
Transport.
The Keyboard.

The PRESIDENT, in moving the adoption of the Report of the Council, said it was stated therein that last year a baronetcy had been conferred upon their Honorary Life Member, Sir Frederick Abel; and it was his pleasant duty to add that in the present year the dignity of Companion of the Bath had been conferred upon their Member, Mr. William Henry Preece, F.R.S., the Engineer-in-Chief and Electrician of the Post Office; and also the Companionship of the Star of India upon their Member, Mr. Thomas Salter Pyne, Engineer to his Highness the Ameer of Afghanistan. The Council had directed a letter of congratulation to be addressed to each of these gentlemen.

During the year the sum of £3,178 of Four per cent. debenture stock in the London and North Western Railway had been converted into £4,237 of Three per cent. debenture stock, as shown in the balance sheet. The odd 6*s.* 8*d.* had been received in cash, and had therefore been deducted from the investments.

The cost of back numbers of the Proceedings had been withdrawn from the capital account of the Institution. This had been done in deference to a suggestion made at the last Annual General Meeting; and on the recommendation of the auditor the cost was stated on both sides of the balance sheet, without being added to capital. Every member could therefore deal with this amount according to his own liking, while the capital was not inflated by a debatable item.

With regard to Research, he was glad to mention that, in addition to the subjects alluded to in the Report, the Council had accepted an invitation to send a representative of the Institution to attend a series of Experiments on a large scale upon the use of Ropes and Belts for the Transmission of Power, which were being undertaken by the Société Industrielle du Nord de la France at Lille. The President of that Society had sent a courteous letter inviting himself to go over, or to send someone to take part in the experiments. The Council had therefore deputed Professor Capper, of King's College, London, a Member of this Institution, and had instructed him to represent the Institution of Mechanical Engineers at these highly important trials. Mr. Capper had already attended a preliminary meeting at Lille, and had sent in a preliminary report, which showed that their friends in France were really taking up the matter in earnest, and were going to expend a great deal of money upon it. The expenditure of the Institution would be the outlay necessary to send a representative of Mr. Capper's qualifications over to attend the trials and to bring back materials, which he would collect for a paper on the conduct and results of the experiments. The Institution of Mechanical Engineers he thought should be congratulated upon the opportunity of taking part in such important experiments.

The motion for the adoption of the Report of the Council with the statement of accounts was then put to the Meeting, and agreed to.

The President reminded the Members that at the present meeting the appointment had to be made of an Auditor for the current year.

On the motion of Mr. David Joy, seconded by Mr. Wallis R. Goulty, it was unanimously resolved that Mr. Robert A. McLean, chartered accountant, 1 Queen Victoria Street, London, be re-appointed to audit the accounts of the Institution for the present year, at a remuneration of Twenty-five Guineas.

The PRESIDENT said that, in pursuance of the notice given on behalf of the Council at the last General Meeting, he had much pleasure in moving the following italicised addition to By-law 15:—"Any Member, Associate Member, or Associate, whose subscription is not in arrear, may at any time compound for his subscription for the current and all future years by the payment of Fifty Pounds, *if paid in any one of the first five years of his membership. If paid subsequently, the sum of Fifty Pounds shall be reduced by One Pound per annum for every year of Membership after five years.* All compositions shall be deemed to be capital moneys of the Institution."

Mr. JOSEPH ADAMSON did not see why the stipulation with regard to the first five years of membership should be introduced. It seemed to him that the effect would be that all who had been members for more than five years would thereby be handicapped to the extent of five years in relation to a new member just elected. That is to say, it was not till the sixth year of membership that the composition would be reduced at all, and then only £1; so that in the sixth year of membership the composition would be £49, while a new member joining at the very time when the older member was paying £49 could compound at once for £50. Looking at the proposal in another way, a member of twenty years' standing would be able to compound for £35, and would then have contributed altogether £95 to the Institution; whereas a new member compounding on election would pay only £50. His remarks were offered in no spirit of opposition to the proposal of the Council, but simply because he did not see why the new members should have what appeared to him to be an advantage over the older.

The PRESIDENT pointed out that the older members, it would be agreed, had of course had value to some extent for their money.

Professor KENNEDY said it would be noticed that the proposed addition to the existing by-law would produce no alteration in any individual instance until after the first five years of membership.

Under the existing by-law any one, whether elected last year or twenty years ago, could compound by payment of £50 at any time. If the proposal now made were adopted, then all who had been members for more than five years could compound for something less. There was no distinction between members who were joining now and those who had joined previously, except that those of more than five years' standing got a larger reduction in proportion to the length of their membership beyond five years.

Mr. J. Macfarlane Gray wanted no alteration to be made until the proposal was adopted which he had advocated three years ago, that any Member having paid his subscription for thirty years should thenceforth have nothing more to pay (Proceedings 1891, pages 27–45).

The President said the Council had given anxious consideration to the present proposal for some time past, and upon the whole it seemed to them a fair arrangement. At any rate he thought it was worth while giving it a fair trial, in order to see how it worked.

The resolution was then put to the meeting, and carried by a large majority.

The President next moved the following italicised addition to By-law 29:—"All Papers shall be submitted to the Council for approval, and after their approval shall be read by the Secretary at the General Meetings, or by the Author with the consent of the Council; *or, if so directed by the Council, shall be printed in the Proceedings without having been read at a General Meeting.*"

The addition to the By-law was unanimously agreed to.

The President announced that the Ballot Lists for the election of Officers for the present year had been opened by a committee of the Council, and that the following were found to be elected:—

PRESIDENT.

Alexander B. W. Kennedy, F.R.S., . .	London.

VICE-PRESIDENTS.

Edward P. Martin, ...	Dowlais.
E. Windsor Richards, ...	Low Moor.

MEMBERS OF COUNCIL.

Arthur Keen, ...	Birmingham.
William H. Maw, ...	London.
James Platt, ...	Gloucester.
T. Hurry Riches, ...	Cardiff.
William H. White, C.B., LL.D., F.R.S., .	London.

In consequence of the election of Mr. Edward P. Martin as a Vice-President, the vacancy thereby occasioned among the Members of Council had been supplied by the Council by the appointment of Mr. Benjamin A. Dobson as a Member of Council for the present year, his name standing next highest in the voting for the election at this Meeting.

The Council for the present year will therefore be as follows:—

PRESIDENT.

Alexander B. W. Kennedy, F.R.S., . .	London.

PAST-PRESIDENTS.

Dr. William Anderson, F.R.S., . . .	London.
The Rt. Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., ...	Newcastle-on-Tyne.
Sir Lowthian Bell, Bart., F.R.S., . .	Northallerton.
Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S., ...	London.
Sir Edward H. Carbutt, Bart., . . .	London.
Charles Cochrane, ...	Stourbridge.
Jeremiah Head, ...	London.
John Ramsbottom, ...	Alderley Edge.
John Robinson, ...	Leek.
Joseph Tomlinson, ...	London.
Percy G. B. Westmacott, ...	Newcastle-on-Tyne.

VICE-PRESIDENTS.

Sir James N. Douglass, F.R.S., . . .	London.
Sir Douglas Galton, K.C.B., D.C.L., F.R.S., .	London.
Edward B. Marten, ...	Stourbridge.
Edward P. Martin, ...	Dowlais.
Sir James Ramsden, ...	Barrow-in-Furness.
E. Windsor Richards, ...	Low Moor.

MEMBERS OF COUNCIL.

John A. F. Aspinall, ...	Horwich.
William Dean, ...	Swindon.
Benjamin A. Dobson, ...	Bolton.
Dr. John Hopkinson, F.R.S., . . .	London.
Samuel W. Johnson, ...	Derby.
Arthur Keen, ...	Birmingham.
William Laird, ...	Birkenhead.
John G. Mair-Rumley, ...	London.
Francis C. Marshall, ...	Newcastle-on-Tyne.
Henry D. Marshall, ...	Gainsborough.
William H. Maw, ...	London.
James Platt, ...	Gloucester.
T. Hurry Riches, ...	Cardiff.
William H. White, C.B., LL.D., F.R.S., .	London.
J. Hartley Wicksteed, ...	Leeds.

Dr. Anderson, in retiring from the Presidency, said all good things came to an end, and it was now his duty to resign the chair which he had occupied for the last two years, and to ask his esteemed friend Professor Kennedy to take it. In doing so, he must in the first instance thank the Members for the support and consideration which they had given him. He likewise wished to take the opportunity of thanking the Council for their assiduous attention to the business of the Institution; and to express the gratification which he was bound to feel, and did feel deeply, at the harmony and good fellowship and good feeling that had prevailed amongst them for the two years during which he had had the distinguished honour to occupy this post.

Professor Kennedy, on taking the chair as President, said he had to thank the Members most sincerely for the honour they had done him in electing him as President of the Institution for the ensuing year. He regretted greatly that two of his colleagues, Vice-Presidents senior to himself both in age and membership, had found themselves unable on account of ill health to undertake the duties of the Presidency which would naturally have devolved upon them. As however the choice of the members had under these circumstances fallen upon himself, in spite of his endeavour to make it fall upon somebody else, he could only say that he would devote himself heartily to their service during the time he was in the chair, and would endeavour to make himself as worthy as he could to be a successor of the distinguished engineers who had occupied the chair before him.

Mr. Jeremiah Head, as the senior Past-President present, said it became both his duty and his privilege to ask the meeting to accord a most hearty vote of thanks to Dr. Anderson, the retiring President, for his services in the chair during the last two years. Since the year 1847, when the Institution was established under the presidency of George Stephenson, there had been a great many Presidents who had deserved their thanks, and through whose efforts, combined with those of the Council and Members, the Institution had been worked up to its present high state of prosperity; but among all those Past-Presidents there were none who had been more constant in attendance to their duties, more celebrated for their urbanity and courtesy to everybody, than Dr. Anderson. They all remembered his presidential address, and how much they enjoyed it and how much they had learnt from it. They remembered also the way in which he had performed the duties of President at Portsmouth and at Middlesbrough, as well as at the several intermediate meetings held in London. The members he was quite sure would agree in the statement that their retiring President could not have performed his duties in a pleasanter and more efficient way. They had heard from the Report of the Council that the Institution had by no means gone back during the last two years; it had in fact gone

ahead greatly, and the impetus given and continued to it by Dr. Anderson would he was sure continue under the presidency of his successor. He would therefore ask the Members to give full consideration to the resolution that he had the honour of placing before them, namely that their very best thanks should be given to Dr. Anderson.

Mr. CHARLES COCHRANE, Past-President, said it devolved upon him to second this vote of thanks, which would receive the hearty approval he was sure of every one present; for not only had Dr. Anderson rendered all these services to the Institution so faithfully during the past two years, but he had done it despite his important engagements as a national servant, and had appeared regularly at their general meetings, and had helped them materially both at Portsmouth and at Middlesbrough. On their visit to Portsmouth the members were in a large way indebted to his influence for obtaining access to the factories there. That he had done all this created a deep debt of gratitude from every member. He had great pleasure in seconding the vote of thanks proposed to the retiring President.

The PRESIDENT, in putting the resolution, said he could not do so as a mere formality, but rather as a matter of special personal interest. They were all proud of their retiring President, and they took it as a high honour to the engineering profession when Dr. Anderson was not long ago elected to the important national position which he now held. In the event of war unhappily breaking out, the possibility of keeping out of it, or the possibility of success or even of security if this country had unfortunately to enter into it, depended largely upon the state of preparation of the department which was administered by Dr. Anderson. The Members were all of them glad, and the country might well be glad, that the Ordnance Factories were under the direction of so thorough a mechanical engineer, who was also a man of such sound judgment, so incorruptible, and so just in all his dealings, as Dr. William Anderson. He had therefore the greatest pleasure in

putting the resolution, that a most hearty vote of thanks be given to him for his conduct in the chair.

The resolution was carried unanimously with applause.

Dr. ANDERSON thought he really did not deserve half the handsome things that had been said about any services which he had been able to render to the Institution. When he accepted the presidency, he had been rather afraid lest the somewhat exacting official duties devolving upon him might prevent his paying as much attention to the interests of the Institution as he should wish to do; but he must say that his chiefs at the War Office had been exceedingly indulgent, and so far from grudging the time necessary to be placed at the disposal of the Institution they had rather encouraged him, because they were perfectly alive he believed to the fact that now-a-days the mechanical engineers were destined to play a most important part in an eventuality such as that to which the President had alluded. Therefore as the defences of the country were now of a highly intricate and mechanical nature, it was felt that anything which would help on the Institution of Mechanical Engineers must be for the national advantage; and he presumed it was for that reason that he had been enabled to give the time that was necessary to its interests. He thanked the Members exceedingly for the warm manner in which they had received the flattering vote of thanks which had been submitted to them; and he hoped the fact that he had retired from the presidential chair would not in any way interfere with his constant attendance at the meetings in time to come.

The PRESIDENT said he had the gratification of announcing that the Summer Meeting of the Institution in the present year would be held in Manchester, under the auspices of the Right Honourable the Lord Mayor, Anthony Marshall, Esq., supported by the Worshipful the Mayor of Salford, Alderman W. H. Bailey, who was a well-known Member of this Institution. As the Members were

doubtless aware, enterprises of great engineering interest and novelty were now on the point of completion in Manchester, or were actually completed already, including the Ship Canal, the Electric-Light Works, the Hydraulic-Power Works, the Sewage Works, and the Thirlmere Water Works. It was hoped that the Members of the Institution would thus enjoy an opportunity in the summer of making a closer acquaintance with these great works than they might as yet have been able to obtain.

The following Paper was then read and partly discussed :—

"Research Committee on Marine-Engine Trials: Abstract of results of Experiments on Six Steamers, and Conclusions drawn therefrom in regard to the efficiency of Marine Boilers and Engines"; by Professor T. HUDSON BEARE, F.R.S.E., of London.

At Ten o'clock the Meeting was adjourned till the following evening. The attendance was 109 Members and 108 Visitors.

The ADJOURNED MEETING was held at the Institution of Civil Engineers, London, on Friday, 2nd February 1894, at Half-past Seven o'clock p.m.; Professor ALEXANDER B. W. KENNEDY, F.R.S., President, in the chair.

The Discussion upon Professor Beare's Paper on the Marine-Engine Trials of the Research Committee was resumed and concluded.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated at Ten o'clock. The attendance was 82 Members and 108 Visitors.

RESEARCH COMMITTEE ON MARINE-ENGINE TRIALS.

ABSTRACT OF RESULTS OF EXPERIMENTS ON SIX STEAMERS, AND CONCLUSIONS DRAWN THEREFROM IN REGARD TO THE EFFICIENCY OF MARINE BOILERS AND ENGINES.

BY PROFESSOR T. HUDSON BEARE, F.R.S.E., OF LONDON.

The Experiments with which the present paper deals in an abstract form are those reported at previous meetings of the Institution, and published with the discussions thereon in the Proceedings of the four years 1889–92. The six steamers, of which the engines and boilers were tested in these trials, were the "Meteor," 1889, pages 235–306; the "Fusi Yama," "Colchester," and "Tartar," 1890, pages 203–290; the "Iona," 1891, pages 200–288; and the "Ville de Douvres," 1892, pages 136–197.

Steamers.—The six steamers were of very different types; their leading dimensions and other particulars are summarised in the accompanying Table 16 (page 34).

The "Meteor" was tested during a run south from Leith to London under ordinary working conditions, that is with natural draught. Her boilers are designed to work with forced draught on the run north in order to do the run five hours quicker, the engines developing therefore much greater power than they did during the trial; in considering the results this fact must be clearly borne in mind. She was built and engined in 1887, and her engines had been overhauled about three months before the trial, which lasted 17 hours 9 minutes, with weather fair.

TABLE 16.—*Steamers; dimensions and speed on trial.*

Steamer.	Description.	Owners.	Makers of Engines.	Length.	Breadth.	Depth moulded.	Draft on trial.	Displacement on trial.	Mean Speed on trial.
				Feet.	Feet.	Feet.	Ft. Ins.	Tons.	Knots.
Meteor	Screw; triple-expansion. Leith and London. Cargo and passengers.	London and Edinburgh Shipping Co.	J. & G Thomson, Clydebank.	261·0	32·1	19·3	15 1½	2,090	14·6
Fusi Yama	Screw; compound. Cargo coaster.	Gellatly, Hankey, Sewell & Co.	M. Samuelson, Hull.	214·3	29·3	20·5	18 11¾	2,175	—
Colchester	Twin-screw; compound. Harwich and Antwerp. Passengers.	Great Eastern Railway.	Earle's Shipbuilding & Eng. Co., Hull.	281·0	31·0	15·3	12 0½	1,675	14·4
Tartar	Screw; triple-expansion. Large cargo.	Gellatly, Hankey, Sewell & Co.	T. Richardson & Sons, Hartlepool.	332·0	38·0	27·0	12 0	2,250	—
Iona	Screw; triple-expansion. Large cargo.	Herskind and Woods.	W. Gray & Co., West Hartlepool.	275·1	37·3	21·8	20 7½	4,430	8·6
Ville de Douvres	Paddle; compound. Dover and Ostend. Mails and passengers.	Belgian Government.	Société Cockerill, Seraing.	271·0	29·0	15·5	9 0¾	1,090	17·1

The "Fusi Yama" was tested during a run down Channel from Gravesend to Portland. Her engines were built in 1874, and immediately before the trial had been overhauled by Messrs. Rait and Gardiner on behalf of her owners, by whom she had just been purchased. As the pistons had been leaking, new spring-rings were fitted to them, but the cylinders were not re-bored; consequently it is probable that the rings had not worn down to the cylinder shape by the time of the trial. The trial lasted 14 hours 9 minutes; weather fair at first, rough at finish.

The "Colchester" had just undergone her first overhaul by Messrs. Earle's Shipbuilding and Engineering Co. Her engines were built in 1888–9. The run was made from Hull southwards and then to Harwich, the trial lasting 11 hours, weather very fine.

The "Tartar" had arrived from Australia a week before the trial. The engines and boilers, which were built in 1887, had been opened out, cleaned, and overhauled, and the cargo discharged; the trial was made therefore with the ship light, only in water ballast. The run was down Channel, and lasted 10 hours 5 minutes; the weather was rough.

The "Iona" also had just arrived from a voyage, and her engines had been overhauled by the makers immediately before the trial. She was built and engined in 1889. The trial was made on a run south from the Tyne, and lasted 16 hours, the weather being fair.

The "Ville de Douvres" before the trial had been running for about eighteen months on her regular route between Dover and Ostend, having been delivered by the builders to the Belgian Government in February 1890. She was overhauled beforehand, and was tried on a special run from Ostend up the North Sea and back. The trial lasted 9 hours, with fair weather throughout.

In summarising the results of these six trials, it will be most convenient to deal with the boilers and engines separately. The various dimensions for each will be given in a condensed form, and then the results obtained during the trials; finally from these results any conclusions which seem to be brought out by the figures will be stated, and any inferences as to the influences of the varying

conditions on the general efficiency of the machinery. The boilers, as the generators of the steam afterwards used by the engines, will in the natural order be dealt with first.

General description of Boilers.—There were three single-ended sets, namely those of the "Fusi Yama," "Iona," and "Ville de Douvres"; and three double-ended sets, those of the "Meteor," "Colchester," and "Tartar." It seems advisable therefore to group the boilers under these two heads. Natural draught was used with all the double-ended boilers, and also with the single-ended set of the "Fusi Yama"; while forced draught was used with the other two single-ended sets. The forced draught for the boilers of the "Iona" was obtained by closing the fronts of the ash-pits, and passing air into them through gridiron valves, from a trunk into which a fan forced the air at a pressure of 0·86 inch of water; a supplementary supply from a branch trunk was also delivered into the combustion chambers through perforated plates, securing therefore small streams of air to mix with the gases after they had passed the furnace bridge, in order to promote perfect combustion in the flame-box. The "Ville de Douvres" on the other hand had closed stoke-holds, with an average air-pressure in them of 0·7 to 1·0 inch of water, the air being supplied by centrifugal fans.

The principal over-all dimensions are given in Table 17. The following additional particulars will probably be found useful in comparing the results obtained with these boilers.

"Meteor." Fox's corrugated flues are used; and the furnaces and tubes at the opposite ends of the boiler open out into common combustion-chambers, of which each boiler has three, one common to each pair of opposite furnaces. As already mentioned, the boiler has been designed to work with forced draught as well as with natural draught.

"Colchester." The boilers have large steam drums 4 feet diameter and 16 feet long; and one common combustion-chamber for each end of the boiler. The furnaces are plain flues. Henderson's fire-bars were in use, mainly with the object of securing a more rapid rate of combustion.

TABLE 17.—*Boilers.*

Steamer.		Number of Boilers.	Diameter.		Length.		Number of Furnaces in each boiler.	Fire-Grate. Width.		Fire-Grate. Length.		Tubes. External Diameter.	Tubes. Length.		Funnels. Number.	Funnels. Internal Diameter.		Funnels. Height.		Material used.
		No.	Ft.	Ins.	Ft.	Ins.	No.	Ft.	Ins.	Ft.	Ins.	Ins.	Ft.	Ins.	No.	Ft.	Ins.	Ft.	Ins.	
Meteor .	Double-ended	2	13	6	16	0	6	3	3	6	0	2½	6	4½	1	7	3	61	0	Steel
Colchester	Double-ended	2	13	0	18	3	6	3	4	5	6	3½	6	7⅝	2	5	5	47	0	Iron
Tartar .	Double-ended	2	13	0	14	9	4	3	8	5	6	3	5	7¼	1	7	0	57	0	Steel
Fusi Yama	Single-ended	1	13	3¾	11	0	3	2	11½	5	10	3¾	7	5	1	4	6½	43	2	—
Iona .	Single-ended	2	13	3	10	0	2	3	6	3*	9	3	6	10⅜	1†	6	3	51	9	Steel
Ville de Douvres	Single-ended	4	13	0	10	0	3	3	0	6	6¾	2½	7	1⅝	2	5	3	49	8	Steel shells, the rest Iron

* Length on trial 3 feet only.

† A damper is placed in funnel 17 ft. 8 ins. above fire-bars.

TABLE 18.—*Boilers, summary of observations and relations. See Plate* 1.

Steamer.		Meteor.	Colchester.	Tartar.	Fusi Yama.	Iona.	Ville de Douvres.
Boilers, number of main boilers		2	2	2	1	2	4
„ single-ended or double-ended		double	double	double	single	single	single
Furnaces, total number		12	12	8	3	4	12
Heating surface, total	square feet	6,648	5,820	5,226	2,257	3,160	7,340
„ „ tubes	square feet	5,760	4,770	4,366	1,689	2,590	6,280
Grate area, total	square feet	208	220	161	52	42	236
„ „ per furnace	square feet	17·33	18·33	20·12	17·33	10·50	19·67
Tube surface to total heating surface	per cent.	86·7	81·9	83·5	74·8	81·9	85·6
Total heating surface to grate area	ratio	32·0	26·5	32·5	43·4	75·2	31·1
Tube surface to grate area	ratio	27·7	21·7	27·1	32·5	61·7	26·6
Grate area to flue area through tubes	ratio	—	5·5	4·5	4·0	2·3	6·7
„ „ to area through funnel	ratio	5·0	4·8	4·2	3·2	1·4	5·5
Draught, natural or forced		natural	natural	natural	natural	forced	forced
Barometric pressure	lbs. per square inch	14·90	15·00	14·60	14·80	14·58	14·84
Boiler pressure above atmosphere	lbs. per square inch	145·2	80·5	143·6	56·84	165·0	105·8
Fuel per hour, total	lbs.	4,005	5,742	1,920	987	942	7,380
„ per square foot of grate per hour	lbs.	19·25	26·10	11·93	18·98	22·4	31·3
„ per square foot of heating surface per hour	lbs.	0·602	0·987	0·367	0·437	0·298	1·01
„ per I.H.P. per hour	lbs.	2·01	2·90	1·77	2·66	1·46	2·32
Carbon-value per I.H.P. per hour (*see Plate* 9)	lbs.	1·76	2·65	1·82	2·33	1·49	2·30

Steamer.	Meteor.	Colchester.	Tartar.	Fusi Yama.	Iona.	Ville de Douvres.
Feed-water per sq. ft. of heating surface per hour . lbs.	4·49	7·39	4·13	3·48	2·73	9·02
,, ,, per lb. of fuel . . . . . . lbs.	7·46	7·49	—	7·96	9·15	8·97
,, ,, ,, ,, from and at 212° F. . lbs.	8·21	8·53	—	8·87	10·63	9·84
,, ,, ,, carbon-value, from and at 212° F. lbs.	9·62*	9·34	—	10·10	10·42	9·94
HEAT Balance-sheet. *See Plate* 2.						
Calorific value per lb. of fuel . . . Th. U.	12,770	13,280	14,995	12,760	14,830	14,390
Feed-water takes up . . . . . . per cent.	62 0	62·0	—	67·2	69·2	66·1
Funnel gases carry away . . . . . per cent.	18·5	28·0	22·1	23·5	16·2	26·8
Imperfect combustion . . . . . per cent.	3·6	1·3	0·0	0·0	0·0	0·0
Evaporating moisture in fuel . . . per cent.	1·2	0·4	0·0	0·9	0 0	0·0
Unburnt carbon in ashes . . . . . per cent.	2·9	1·7	1·4	—	1·6	3·1
Balance unaccounted for (radiation) . . per cent.	11·8	6·6	—	8·4	13·0	4·0
Temperature, outer air . . . . . Fahr.	—	55°	55°	55°	62°	64°
,, funnel gases . . . . . Fahr.	791°	835°	477°	578°	452°	910°
,, feed-water . . . . . Fahr.	163°	113°	101°	129·5°	106°	158°
,, boiler steam . . . . Fahr.	363°	324°	362°	304°	373°	342°

* Allowing 3 per cent. for clinker not in chemical analysis.

"Tartar." There are two combustion chambers for each boiler, common to opposite furnaces. Fox's corrugated furnaces are used.

"Fusi Yama." The furnaces and tubes all open into one common combustion chamber; the furnaces are plain flues. A large tall steam dome is carried on the top of the boiler.

"Iona." Purves' corrugated flues are used. The fan for forced draught is driven by a Chandler single-acting high-speed engine developing about 2 H.P. Each furnace opens into its own combustion chamber.

"Ville de Douvres." The forced-draught fans are driven by two Brotherhood engines, each developing about 14 H.P. Each furnace has its own combustion chamber; the flues are plain.

In Table 18 (pages 38–9) is given a complete summary of all the important dimensions and their relation to one another, for grates, heating surface, tubes, and funnels; also the mean steam-pressures during the trials, rates of fuel combustion and water evaporation, and finally a summary of the heat account for each boiler. In Fig. 1, Plate 1, is shown the total feed-water consumption in each of the trials; in Fig. 2 the total fuel consumption; and in Fig. 3 the total revolutions. The heat balance-sheet is also shown in Plate 2, from which is seen at a glance the proportion utilized in the feed-water, the proportion lost in the funnel gases, and the rest of the losses of heat.

Observations made.—In each trial the coal was weighed in baskets hung from spring balances, and then emptied in heaps upon the stoke-hold floors; and the rate of consumption of fuel as well as the amount was determined. The feed in all the trials—except that of the "Ville de Douvres," in which meters were used—was measured by passing it on its way to the boiler through two tanks, which were filled and emptied alternately, thereby again ensuring knowledge of rate as well as of quantity used. The boiler pressures were observed at fixed intervals, as were also the temperatures of air, of feed, and of escaping furnace-gases. Lastly, samples of the furnace gases were taken at fixed times for subsequent analysis; and also samples of the coal and ashes for the same purpose. The air-pressure

in the funnels &c. was measured by U water-gauges. From these data a fairly complete heat-account for the boilers can be calculated.

Fuel.—The coal used on the different trials varied considerably in quality. A summary of the chemical analysis, carbon value, calorific value, and evaporative power, is given in Table 19 (page 42) for each steamer. It will be seen that the coal used in the "Meteor," "Colchester," and "Fusi Yama" trials was much inferior to that in the case of the three other vessels; and that in the "Meteor" and "Fusi Yama" coal the moisture present was great, over 10 per cent. for the "Meteor." The calorific values are all calculated on the assumption of the complete combustion of all the hydrogen present, making allowance for the latent heat of the steam so formed.

Ashes.—The quantities and percentages of ashes weighed out at the end of the trials, with particulars as to the cleaning of the fires, are given in Table 20 (page 43). In every trial the fire was cleaned at the end, and the resulting clinker and ashes weighed; a sample was taken, and afterwards by ignition the proportion of unburnt carbon in it was estimated. In the heat balances given in the various reports no attempt has been made to estimate the proportion of loss due to the unburnt carbon present in the ashes; it may however be worth while to estimate it per pound of coal burnt, more especially as the balance unaccounted for, which must be ascribed mainly to this and to radiation, varies considerably. In Table 20 are given the total ashes and their percentage of the total fuel put on the fires; also the percentage of carbon in the ashes, and the equivalent total carbon therefore lost in the whole of the ashes. The results expressed as percentages of heat-value in the fuel vary from 1·36 to 3·10 per cent. It has been assumed that the balance of the mineral matter, found in the fuel by chemical analysis and not shown in the ashes, either went up the funnel as fine dust, or more probably remained on the fire-bars as clinker at the end of the trial. If these percentages are added to those for feed-water evaporated, loss of heat in furnace gases, imperfect combustion &c., the balance, apart from errors of observation, can be put down only to radiation.

TABLE 19.—*Fuel.*

Steamer.	Name of Coal.	Analysis of Fuel as used.					Per Pound of Fuel.		
		Carbon.	Hydrogen.	Water.	Ash.	Nitrogen, Sulphur, Oxygen, &c., by difference.	Equivalent Carbon-value.	Calorific value.	Evaporative Power. Lbs. of Water from and at 212° Fahr.
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Lb.	Th. Units.	Lbs.
Meteor	Scotch, Shawfield.	70·31	4·88	10·68	3·46	10·67	0·878	12,790	13·24
Colchester	Monk Bretton, Yorks, & Hucknall & Shireoaks, Notts.	71·89	5·42	4·25	4·08	14·36	0·913	13,280	13·75
Tartar	Welsh, Penrikyber.	87·98	4·22	1·07	3·42	3·31	1·031	14,995	15·52
Fusi Yama	West Hartley, Tyne.	70·85	4·71	8·60	5·11	10·73	0·878	12,760	13·21
Iona	Walbottle, Tyne.	82·34	5·47	1·94	2·90	7·35	1·020	14,830	15·35
Ville de Douvres	Block Fuel.*	84·65	3·98	2·41	5·30	3·66	0·99	14,390	14·90

* Made at Marcinelle and Chatelineau, Belgium.

TABLE 20.—*Ashes.*

Steamer.	Cleaning of Fires.	Ashes.		Carbon in Ashes.		Loss of heat from unburnt carbon in ashes.	
		Total.	Proportion of total Coal.	Proportion.	Total.	Per minute.	Proportion.
		Lbs.	Per cent.	Per cent.	Lbs.	Th. Units.	Per cent.
Meteor	End of trial only.	4,477*	6·51	—	—	24,580§	2·88
Colchester	do.	2,220†	3·5	43·73	962	21,420	1·68
Tartar	do.	291‡	2·2	65·53	185	6,506	1·36
Fusi Yama	do.	278	2·0	—	—	—	—
Iona	Once during trial.	430	2·9	56·19	242	3,659	1·57
Ville de Douvres	Once during trial.	4,760	7·2	42·86	2,040	54,930	3·10

* Consisting of 1,671 lbs. ashes and 2,806 lbs. clinker, equivalent to 2·43 and 4·08 per cent. of the total coal.

† Actual quantity weighed out, 2,890 lbs.; but this included ashes made in getting up steam, and in preliminary run before start of trial.

‡ For a period of 6 hours 53 minutes only.

§ This is an estimate of the loss owing to the fact that, in selecting lumps for chemical analysis, bad stony lumps were rejected.

Feed-Water.—There are several points of importance in the various trials, to which attention must be drawn before dealing with the actual results.

"Meteor." All the steam corresponding with the measured feed went to the main engines, and to a small Worthington pump which fed the boilers. The circulating-pump engine, dynamo engine, and all the deck engines were supplied with steam by a donkey boiler. The supplementary feed was not separately measured; it was drawn from the exhaust of the circulating-pump engine and dynamo engine. The feed was heated in the hot well up to 163·1° Fahr. by means of an apparatus devised by the chief engineer.

"Colchester." All the steam from the measured feed went to the main engines; only one feed-pump was in use; the supplementary feed was not measured separately. The circulating-pump engine and others were all worked off a donkey boiler. The mean feed temperature was 113° Fahr.

"Tartar." All the steam from the measured feed went to the main engines, the auxiliary engines being worked from the donkey boiler. One of the main feed-pumps was used at start; but later the donkey pump, drawing its steam from the main boilers; the supplementary feed was not measured separately. Mean feed temperature 101° Fahr.

"Fusi Yama." All the steam from the measured feed went to the main engines; the supplementary feed was not measured separately. The feed was supplied by the main feed-pumps. Mean feed temperature 129·5° Fahr.

"Iona." All the steam from the measured feed went to the main engines. Here the circulating pumps and feed-pumps were all worked by the main engines. The supplementary feed was separately measured. The average feed temperature was 106° Fahr.; in ordinary working the feed is heated to a much higher degree than this, by draining the jackets into the feed suction-pipe.

"Ville de Douvres." The feed, measured by a Kennedy positive piston water-meter, went to the main boilers, and supplied steam not only to the main engines but also to the auxiliary engines. The average feed temperature was 158° Fahr.; there was no feed heater.

It will be seen therefore that in some cases the circulating pump was driven by an independent engine, in others by the main engines.

TABLE 21.—*Feed-Water, in relation to Boiler and Fuel.*

Steamer.	Feed-Water used per hour.	Mean Temperature.		Heat in Boiler.		Water evaporated from and at 212° Fahr.	
		Feed-Water.	Boiler.	Taken up per lb. of Steam.	Utilized per lb. of Fuel.	Per lb. of Fuel.	Per sq. foot of heating surface per hour.
	Lbs.	Fahr.	Fahr.	Th. Units.	Th. Units.	Lbs.	Lbs.
Meteor . . .	29,860	163·1°	363°	1,062	7,922	8·21	4·94
Colchester	43,020	113·0°	324°	1,100	8,240	8·53	8·42
Tartar	21,564	101·0°	362°	1,123	—	—	—
Fusi Yama . . .	7,860	129·5°	304°	1,077	8,570	8·87	3·88
Iona	8,616	106·0°	373°	1,122	10,265	10·63	3·17
Ville de Douvres . .	66,180	158·0°	342°	1,060	9,509	9·84	9·90

As however this is a question affecting the efficiency of the engines rather than of the boilers, it will be advisable to defer any remarks on this point. In Table 21 (page 45) are given in a convenient form for reference certain data as to feed, evaporation &c. Neglecting the results of the "Tartar," it will be seen that the single-ended boilers on an average evaporate from and at 212° Fahr. 10·15 lbs. of water per lb. of carbon-value, as against only 9·48 lbs. for the double-ended boilers.

Priming. — This important subject was brought into great prominence from the results of the "Tartar" trial. In the earlier trials no attempt was made to measure the priming, because its presence was not suspected; and the results of those trials gave no reason for supposing that such an action was taking place. In the two trials after that of the "Tartar" however, it was determined to measure this factor; this was done in both trials by means of the salt test. Unfortunately with the "Iona" the apparatus broke down, and only one test was made, which showed priming to the amount of 2·87 per cent. In the "Ville de Douvres" trial more tests were made, all of which showed practically no priming.

The case of the "Tartar" is one which must be dealt with somewhat fully. It is clear that the whole of the measured feed cannot have been evaporated by the quantity of coal used; if it had been, 84·1 per cent. of the total heat of the coal would have been spent in doing it, leaving only 15·9 per cent. for loss in chimney gases, radiation, &c. The analysis of gases however, and the chimney temperature, enable us to calculate that 22·1 per cent. must have gone away in the waste gases. A careful inspection of the log sheets has revealed nothing in the least anomalous in the observations. Unless therefore nearly 20 per cent. of the feed-water which was measured through the tanks never reached the boilers at all, the author can see no other explanation than priming. The amount of the supplementary feed being normal, such a loss between feed tank and boilers would at once have shown itself in the gauge glasses; but as a matter of fact, though the water-level in the boiler did fall, it was very little, and corresponds in amount to less than 1 per cent.

of the total feed. As to conditions likely to cause priming, there is the fact recorded that the ship was light and the weather stormy, so much so that the trial was carried on with difficulty towards the end. There is every probability therefore that the water in the boilers was in a state of violent agitation, and by the action of the stays would be broken up into foam, a condition most likely to lead to priming. That there was considerable priming the author believes is shown by calculations from the indicator diagrams as to the amount of steam actually present in the cylinders. Considering first the high-pressure cylinder, there was present just after cut-off behind the piston, that is including the clearance volume, 3·39 lbs. of steam per revolution; while just before the point of release this had become 4·33 lbs., being a gain of 0·94 lb. or over 27 per cent., equivalent to 18 per cent. of the feed. There was no jacket in use on this cylinder; and on making a similar calculation for the three unjacketed engines, it is found that the total steam at the end of the stroke is almost exactly what it was at the beginning, the re-evaporation being very slight. [See also pages 73–4.] Unless therefore either the piston (see also page 139) or the valves were leaking badly, which there is no reason to suppose as the engine had just been overhauled, this increase must have been caused by evaporation of water in the cylinder itself. It seems to the author that this difference can possibly be explained by the priming; with the steam there came over in a finely divided state water intimately mixed up with the whole body of the steam. As the steam expanded after cut-off and fell in pressure, this water evaporated. This action would be confined to the core of the mass of steam; that which came in contact with the walls and surfaces would behave as usual, condensing and forming a fine film all over the surfaces, and owing to the absence of jackets would be only very slightly re-evaporated. There is some difficulty however in this explanation, as it is not clear where the heat necessary for this considerable evaporation can have come from; the loss of internal energy in the steam as it fell in pressure is not sufficient, as proved by repeated calculations. The great amount of water noted in the intermediate cylinder the author

TABLE 22.—*Funnel Gases.*

Steamer.	Analyses of Gases by weight. *See Plate 3.* Carbonic Acid.	Carbonic Oxide.	Oxygen.	Nitrogen.	Temperature of Gases, and Height above boiler where taken *See Plate 4.*		Dry Air per lb. of Fuel. Theoretical	Actual. *See Plate 4.*	Specific Heat of Gases.	Heat lost in Gases. *See Plate 4.*	Chimney Draught in inches of water.
	Per cent.	Per cent.	Per cent.	Per cent.	Fahr.	Feet.	Lbs.	Lbs.	Sp. Heat.	P. cent.	Inches.
Meteor* . .	18·17	0·75	5·71	75·37	791°	12	9 8	13·0	—	18·5	0·31
Colchester .	13·59	0·22	10·78	75·41	835°§	—	10·1	18·5	0·238	28·0	{0·38 F {0·34 A
Tartar . .	9·98	0·00	14·19	75·83	477°	—	11·6	31·6	0·238	22·1	0·22
Fusi Yama* .	11·17	0·00	12·48	76·35	578°	—	9 8	22·8	—	23 5	0 28
Iona . .	12·12	0·00	12·01	75·87	452°	30	11·4	24·5	0·243	16·2	0 25
Ville de Douvres	16·84	0·00	8·44	74·72	910°§	—	11·1	17·9	0·243	26·8	1·07

* Only one sample of gases from the "Meteor," and only two from the "Fusi Yama."

§ Temperature only approximate, because in about 37 per cent. of the readings in the "Colchester," and in nearly all in the "Ville de Douvres," it exceeded the limit of the thermometer.

F = Forward funnel; A = After funnel.

thinks can be explained by initial condensation in the high-pressure cylinder, apart altogether from priming; the film of water deposited on the high-pressure cylinder surfaces, and not entirely re-evaporated owing to the jacket not being in use, would be swept into the receiver and collect there, and be eventually carried into the intermediate cylinder. The whole difficulty, the author feels, points to the absolute need of priming tests in all such trials, if the results are not to be vitiated by an unknown quantity as in this case. Under normal working conditions most probably priming would be unlikely with such boilers; but the fact that it did occur proves the need of always testing for it. It is noteworthy that in the "Iona," where the one test did show priming, though less than 3 per cent., there was great condensation in the high-pressure cylinder.

Funnel Gases.—In every trial samples of the furnace gases were regularly drawn off, and afterwards analysed by Mr. Charles J. Wilson. In the "Meteor" trial the samples were unfortunately all spoiled except one: and therefore the results in this case are not so valuable as in the other trials. The temperature of the furnace gases was also measured by a special mercury thermometer. In Table 22 are given the mean chimney-draught and temperature

TABLE 23.—*Funnel Gases; Weight, Volume, and Velocity.*

Steamer.	Funnel Gases leaving tubes per min. in each boiler.		Sectional Area of Tubes in each boiler.	Velocity of Gases through tubes.	Tube Surface per lb. of gases per minute.
	Weight.	Volume.			
	Lbs.	Cub. Ft.	Sq. Feet.	Ft. p. min.	Sq. Feet.
Meteor . .	467	14,690	—	—	6·16
Colchester .	933	30,360	20·00	1,518	2·56
Tartar . .	522	12,280	17·89	686	4 19
Fusi Yama .	391	10,200	13·00	785	4·32
Iona . .	200	4,590	9·13	503	6·49
Ville de Douvres	581	20,010	8·81	2,272	2·70

and the analyses of the gases by weight; also the actual weight of air used per lb. of fuel, and the percentage of heat lost in the furnace gases. In Plate 3 are shown the analyses of the gases; also in Fig. 6, Plate 4, their temperature, and in Fig. 7 the heat they carry away, and the air actually used.

In Table 23 is given the weight of gases which must have passed up the funnel per minute from each boiler; and as the temperature of these gases immediately afterwards is known (Table 22), their volume and the velocity with which they passed out of the tubes into the smoke-box or funnel uptake can be approximately calculated.

When the figures in the fifth column of Table 23 are divided by those in the sixth, the ratios so obtained will give some idea of the relative loss of heat in the waste gases from the different boilers, as follows:—

	Ratios of Velocity of Gases through tubes to per lb. of gases Tube Surface per minute.	Percentages of total heat that are sent up funnels.
Meteor	—	18·5 per cent.
Colchester	594·0	28·0 ,, ,,
Tartar	163·9	22·1 ,, ,,
Fusi Yama	181·7	23·5 ,, ,,
Iona	77·5	16·2 ,, ,,
Ville de Douvres	841·0	26·8 ,, ,,

The temperature of the "Iona" gases was measured at a point 30 feet above the bars, and therefore the velocity through the tubes would be higher than here given, because the actual temperature just after leaving the tubes must have been much greater than that measured.

Air Supply.—In two cases there were double funnels; the air supply has therefore been calculated for each separately, and compared with the rate of combustion of the fuel on the grates, and with the chimney-draught.

In the "Colchester" the air supply per pound of coal was 16·00 lbs. for the forward funnel, and 21·90 lbs. for the aft; while the fuel burnt per square foot of grate per hour was 25·94 lbs. for the forward boiler, and 26·27 lbs. for the aft. The mean

chimney-draught was 0·38 inch of water in the forward funnel, and 0·34 inch in the aft. In the forward funnel the much smaller air supply with nearly 12 per cent. more draught is marked, and seems to point to the fact that it is not possible merely from draught alone to say what are the proportionate quantities of air passing through two furnaces.

In the "Ville de Douvres" the air supply per pound of fuel was 19·07 lbs. for the forward funnel, and 16·78 lbs. for the aft; while the fuel burnt per square foot of grate per hour was 32·1 and 30·44 lbs. respectively. The mean chimney-draught in the two funnels was the same. Here again the figures point to the same conclusion as in the "Colchester."

Radiation.—In the heat balance-sheet given in Table 18, the balance unaccounted for is presumably due in the main to radiation. In order to check this, the external surfaces of the boilers, from which radiation takes place, have been calculated on the assumption that they are plain cylinders closed at each end. This supposition, though not correct, must nevertheless give fairly correct comparative figures, which are shown in Table 24.

TABLE 24.—*Heat lost by Radiation from Boiler Surfaces.*

Steamer.	Radiating Surface.		Difference between Temperature of Steam and of Air.	Heat lost by Radiation.	Heat lost per sq. foot of surface per hour.
	Total.	Per lb. of Fuel burnt per minute.			
	Sq. Feet.	Sq. Feet.	Fahr.	Per cent.	Th. Units.
Meteor . . .	1,929	28·9	308°	11·8	3,120
Colchester .	2,021	21·1	269°	6·6	2,470
Tartar . . .	1,735	54·2	307°	—	—
Fusi Yama . .	730	44·4	249°	8·4	1,450
Iona . . .	1,384	88·1	311°	13·0	1,430
Ville de Douvres	2,696	21·9	278°	4·0	1,580

With a boiler of the locomotive type but with only a low rate of coal consumption, the author has found a loss by radiation of 10 per cent. with a 2-inch coating of non-conducting material. The losses in Table 24 therefore are apparently what would be expected in boilers with the rates of consumption here met with. The high radiation in the "Iona" there can be no doubt is mainly due to the large size of the boilers used for the power developed, and therefore to the excessive radiation-surface per pound of fuel burnt per minute. In the "Meteor" and the "Fusi Yama" it must be remembered that the results can be considered only approximate, owing to the few samples of gas collected.

Boilers, General Conclusions.—The "Tartar," on account of the uncertainty of the amount of priming, must be omitted from consideration. The efficiency of the double-ended boilers is 62 per cent., of the single-ended 67·5; this gain is partly due to less loss in furnace gases, but more apparently to the prevention of imperfect combustion, even with a high rate of fuel consumption. The "Meteor" boilers would in all probability give a higher efficiency with forced draught, the small size of the tubes being a drawback when working with natural draught. The high efficiency of the "Iona" working with such small grates would seem to point to the fact that, by the adoption of some system of forced draught and a reduction in the length of the grates, the efficiency of the average marine boiler would be sensibly increased. At the same time the boilers of the "Ville de Douvres" show that, where a very high rate of fuel consumption has to be obtained from a given boiler, then forced draught and large grates with only the normal proportion of heating surface can be used, and the boiler will still be efficient. The greater loss incurred by sending the furnace gases away hotter is partly counterbalanced by the proportionally smaller radiation per pound of fuel. Unless some plan can be devised for utilizing the waste heat passing away through the chimney, it seems that about 70 per cent. is likely to be the maximum amount utilized of the total heat of the fuel in the present type of marine boiler.

Engines.—In three of the steamers the engines were two-cylinder compound, and in the other three triple compound. They will therefore be discussed in these two groups, and also in regard to jacketing of cylinders, and other points of general design. The two-cylinder compound sets were the "Fusi Yama" ordinary inverted vertical, the "Colchester" twin inverted vertical, both screw engines; and the "Ville de Douvres" inclined paddle engines. None of these had jacketed cylinders. The triple sets were the "Meteor" and the "Tartar" with all three cylinders jacketed, but on the trial of the "Tartar" the intermediate and low-pressure jackets only were in use; and the "Iona" with the high-pressure cylinder jacketed. All of these engines were of the ordinary inverted marine type. Table 25 (page 54) gives their leading dimensions; and Plate 5 shows the cylinder volumes and the relative clearance volumes. The following additional particulars will be of value in considering the results obtained.

"Fusi Yama." The cranks are at right angles, the low-pressure leading. Steam is distributed to each cylinder by a single slide-valve worked by ordinary link-motion. The receiver forms a belt round the high-pressure cylinder.

"Colchester." The two engines are entirely separate, a condenser between being common to both. The cranks are at right angles, the high-pressure leading. The valve-gear is ordinary link-motion. The high-pressure cylinder has a piston-valve, and the low-pressure a double-ported slide. The receiver forms a belt round the high-pressure cylinder.

"Ville de Douvres." The engines are inclined. The high-pressure crank leads, the two cranks being at right angles. The receiver encircles the high-pressure cylinder. The high-pressure cylinder is fitted with a pair of piston-valves, the low-pressure with one; and in each case the gear is the Allan link-motion.

Since there are no jackets to any of these three sets of engines, there are no liners to any of the cylinders.

"Meteor." The cranks follow in the order—high, intermediate, low. The ends of the cylinders are not jacketed, the total length of the jackets being about 4 feet. All the valves are piston-valves,

TABLE 25.—*Engines.* *See Plate 5.*

Steamer.	Cylinders.				Ratios of Volumes.*		Clearance Volumes.†			Condensing Surface, Total.	Revolutions per minute.
	Diameters.			Stroke.	Inter. / High	Low / High	High.	Inter.	Low.		
	High.	Inter.	Low.								
Two-cylinder Compound.	Ins.	Ins.	Ins.	Inches.	Ratio.	Ratio.	P. cent.	P. cent.	P. cent.	Sq. Feet.	Revs.
Fusi Yama . . .	27·35		50 30	33·00		3·42	8·50		5·00		55·59
Colchester . . .	30 00		57 00	36·00		3·70	9 39		6·23	3,000	{86·00 87·10
Ville de Douvres . .	50·12		97·12	72·00		3·84	15·00		12·00	6,540	36·82
Triple Compound.											
Meteor . . .	29·37	44·03	70·12	47·94	2·35	5·89	12·40	9·30	8·02	3,200	71·78
Tartar . . .	26·03	42·03	68·95	42·00	2·64	7·16	14·51	9·25	5·10	2,250	70·00
Iona	21·88	34·02	56·95	39·00	2·46	6·93	12·41	10·11	7·64	1,360	61·10

* Ratio of Volumes swept through by pistons. † Clearance Volumes in percentage of volumes swept through by pistons.

worked by ordinary link-motion; the valves are single for the high-pressure cylinder, double for the others.

"Tartar." The cranks rotate in the sequence—high, low, intermediate. The cylinders are fitted with jackets on the body and on both ends; except the high-pressure cylinder, which has only body and top end jacketed. The valves are piston-valves for the high-pressure and intermediate cylinders, and a double-ported slide-valve for the low-pressure, all worked by Wyllie's elliptical gear, with independent adjustment for the cut-off.

"Iona." The cranks rotate in the order—high, intermediate, low. Only the high-pressure cylinder is jacketed. The valves for the high and low-pressure cylinders are ordinary double-ported, and for the intermediate a Trick slide-valve is used. The intermediate receiver encircles the high-pressure valve-chest and part of the jacket, and the low-pressure receiver another part of the high-pressure jacket.

Observations made.—In addition to those already described in page 40, the following were also made. Indicator diagrams were taken simultaneously from both ends of every cylinder at half-hourly intervals; all engine-room and other gauges and also the counter were read at the same intervals. In the "Iona" trial, diagrams were also taken from some of the pumps and from the receivers. The diagrams were used to determine the power, initial steam-pressures, release pressures, back pressures, and also the quantity of steam present in each cylinder at various points in the stroke. Unfortunately it was not possible to measure the quantity of condensing water used, nor in several of the trials the rise of temperature of this water; there is therefore no possibility of making a complete balance-sheet for the engines, such as was given in the reports for the boilers. Considering the enormous quantity of water used for condensing purposes with such large engines, there does not seem any prospect of successfully measuring it; meters the author thinks are out of the question.

From the observations it is possible therefore to make only two calculations for the balance-sheet: one the total heat received per

TABLE 26.—*Steam Pressures.* *See Plates 6 and 7.*

Steamer.	Mean Steam Pressures per square inch, absolute.		Mean Effective Pressures per square inch.				Exhaust in Low-p. cylinder per square inch.		Vacuum in Condenser per square inch.	
	Boiler.	High. Initial.	High.	Inter.	Low.	Total reduced to Low.	Below atm.	Absolute.	Below atm.	Absolute.
Two-cylinder Compound.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Fusi Yama . . .	71·64	65·10	30·74		10·87	19·90	10·90	3·90	12·48	2·32
Colchester . . .	95·50	{79·30 {74·40	45·65 42·07		13·42} 12·42}	24·80	{10·60 {10·50	4·40} 4·50}	12·49	2·51
Ville de Douvres . .	120·64	104·04	55·49		15·54	30·17	8·78	6·06	10·12	4·72
Triple Compound.										
Meteor. . . .	160·10	149·30	58·46	19·50	12·38	29·90	11·60	3·30	12·17	2·73
Tartar . . .	158·20	136·00	36·89	20·07	7·18	19·80	10·50	4·10	12·90	1·70
Iona	179·58	157·08	46·65	20·44	7·16	21·13	12·74	1·84	13·88	0·70

TABLE 27.—*Power Measurement.*

Steamer.	* Piston Constants.			Indicated Horse-power. *See Plate* 8.			
	High.	Inter.	Low.	High.	Inter.	Low.	Total.
Two-cylinder Compound.	H.P.	H.P.	H.P.	I.H.P.	I.H.P.	I.H.P.	I.H.P.
Fusi Yama . . .	5·36		18·32	168·2		203·1	371·3
Colchester . . .	10·71 10 84		39·55 40·06	490·3 457·9		532·2 499·3	1,022·5 957·2
Ville de Douvres . .	25·99		98·56	1,444·0		1,533·0	2.977·0
Triple Compound.							
Meteor. . . .	11·31	26·00	66·65	662·0	507·0	825·0	1,994·0
Tartar. . . .	7·73	20·42	55 27	283·7	408·5	395·2	1,087·4
Iona	4·41	10·82	30·54	205·6	221·2	218·6	645·4

* Piston Constant = horse-power per pound of mean effective pressure per square inch on piston.

minute by the engines, including therein heat given both to the cylinder steam and to the jacket steam; and the other the useful work done per minute. The ratio of these two quantities gives the actual efficiency of the engines. Unfortunately in the only trial in which all the cylinders were jacketed, the steam condensed in them could not be measured apart from that used in them. What proportion of the heat unaccounted for in the balance-sheet was rejected in the condensing water, and what went in radiation, there is therefore not the means of stating, though by certain calculations the amount can be approximately arrived at in the "Iona" and the "Ville de Douvres."

Power Measurement.—The indicators used were as follows: in the "Meteor" trial, Crosby; in the "Fusi Yama" for the high-pressure cylinder, Darkes, and for the low-pressure, Richards; in the "Colchester," "Tartar," and "Iona" trials, McInnes; and in the "Ville de Douvres," Richards. In all cases the indicators were as close to the cylinders as possible, the connections being short large pipes, free from bends. The instructions for taking diagrams, issued to each observer engaged on this work in any trial, and printed in page 241, 1890, show what great care was taken to ensure accuracy in the diagrams. In Tables 26 and 27 (pages 56–57) are given the results obtained from the diagrams, and also the mean readings from some of the gauges. The diagram in Plate 6 shows the boiler pressure, the initial pressure in the high-pressure cylinder, the mean effective pressure in each cylinder, the exhaust pressure in the low-pressure cylinder, the condenser vacuum, and the barometric pressure. In Plate 7 are shown the whole of the mean indicator diagrams. Plate 8 shows the indicated horse-power in each cylinder.

One of the most striking features in Table 26 is the considerable difference between the average back-pressure in the low-pressure cylinder and the condenser pressure. In Table 28 is shown for each steamer the amount of this difference, and the equivalent increased horse-power which would have been obtained in the low-pressure cylinder, had its back-pressure been the same as that of the

condenser; and this increase would of course have been brought about without the expenditure of any more steam.

As regards the "Ville de Douvres" however, this comparison hardly suffices, because her condenser vacuum was so bad on the day of the trial that the loss was really much more serious. Omitting the "Iona," where a remarkably good vacuum was obtained, the average absolute condenser-pressure in the other four steamers was 2·31 lbs., whilst that in the trial of the "Ville de Douvres" was as much as 4·72 lbs.; a further loss of pressure of 2·41 lbs. per square inch should therefore be allowed for this, which would increase the loss of power by 237·5 horse-power, and make the total percentage 12·4 in the "Ville de Douvres," instead of only 4·4 per cent. In every case therefore, except the "Meteor," this loss is sufficiently great to justify some attempt to diminish it by increasing the size of the

TABLE 28.

Difference between Back-Pressure in Low-pressure Cylinder and Pressure in Condenser; and equivalent Horse-power.

Steamer.	Difference between Back-Pressure in Low-pressure Cylinder and Condenser Pressure per square inch.	Equivalent Horse-power. Actual.	Equivalent Horse-power. Percentage of Total Horse-power developed.
Two-cylinder Compound.	Lbs.	H.P.	Per cent.
Fusi Yama .	1·58	28·94	7·8
Colchester .	1·94	{77·20 77·20}	7·8
Ville de Douvres	1·34	132·10	4·4
Triple Compound.			
Meteor . .	0·57	37·99	1·9
Tartar . .	2·40	132·60	12·2
Iona . .	1·14	34·82	5·4

TABLE 29.—***Feed-Water, in relation to Engine and Power.***

Steamer.	Feed-Water used in main engines.			Heat per minute.			Engine Efficiency.
	Per minute.	Per hour.	Per I.H.P. per hour. *See Plate* 9.	Taken up by Feed-Water. Total.	Taken up by Feed-Water. Per I.H.P.	Turned into Work.	*See Plate* 9.
	Lbs.	Lbs.	Lbs.	Th. Units.	Th. Units.	Th. Units.	Per cent.
Two-cylinder Compound.							
Fusi Yama	131	7,860	21·17	141,100	380·0	15,870	11·2
Colchester	717	43,020	21·73	788,700	398·4	84,630	10·7
Ville de Douvres . . .	1,103	66,180	20·77*	1,092,000	366·8	127,300	11·7
Triple Compound.							
Meteor	497·7	29,860	14·98	528,600	265·6	85,240	16·1
Tartar	359·4	21,564	19·83†	—	—	—	—
Iona	143·6	8,616	13·35	161,100	249·6	27,590	17·1

* Total, including auxiliary engines, 22·23 lbs. per I.H.P. per hour.

† This includes what was most probably priming water.

exhaust passages or other suitable means; from the results with the "Meteor" low-pressure cylinder it seems clear that it can be reduced to a very small amount. It should be stated that these calculations assume the condenser gauges to have been indicating correctly; they were tested only in the "Iona" and "Ville de Douvres."

Another notable point is the considerable wire-drawing of steam between the boiler and the high-pressure cylinder. This is no doubt largely due to the action of the valve-gear, since the gauges on the high-pressure valve-chest show a much closer agreement with the boiler; for instance, with the "Iona" the pressures are—boiler 179·58, valve-chest 174·58, initial in cylinder 157·08 lbs. per square inch. It certainly does not seem worth while to design a boiler to carry such a heavy pressure as 180 lbs. absolute, if nearly 13 per cent. of this is to be lost between the boiler and the first cylinder: though no doubt the superheating produced may lessen initial condensation, and thereby make up the loss.

Feed-Water.—This having already been dealt with very fully in connection with the boilers, it will be necessary to give only a few additional figures, referring the consumption of feed-water to the engine and to the horse-power developed. In the trials of the "Meteor" and the "Colchester" the circulating pump was driven by a separate engine deriving its steam from a separate boiler; while in the "Tartar," the "Fusi Yama," and the "Iona" it was driven by the main engine. In the "Ville de Douvres" trial, both this engine and the fan engines drew their steam from the main boilers; but supplementary trials were afterwards made to determine their steam consumption, and corrections are made in the total feed in the main trial, to allow for the steam they used. In Table 29 the figures apply to the main engines only. The actual economy of the machinery in the "Tartar," the "Fusi Yama," and the "Iona" is therefore really greater in comparison with the other engines than is shown by Table 29, because the rate of steam consumption in the auxiliary engines would be much higher than in the main engines. Plate 9, illustrating Table 29, shows the weight of feed-water used per indicated horse-power per hour, and the engine efficiency; and on

TABLE 30.—*Steam-Jackets.*

Steamer.	Cylinders Steam-Jacketed.	Absolute Steam-Pressure per square inch.						Feed used in Jackets.
		Cylinder Jackets.			High-p. Valve-chest.	No. 1 Receiver.	No. 2 Receiver.	
		High.	Inter.	Low.				
Triple Compound.		Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Per cent
Meteor . . .	High, Inter., Low.	145·9	92·4	71·7	†149·3	51·4	21·1	—
Tartar . . .	* Inter., Low.	—	67·1	28·6	146·0	§60·7	§18·4	3·94
Iona . . .	High.	179·58	—	—	174·58	—	—	‡4·30

* High-pressure jacket was shut off; but steam leaked into it, sufficient to show pressures varying from 14·6 to over 64·6 lbs. absolute.

† This is the mean initial pressure in the high-pressure cylinder.

§ These are the pressures in the intermediate and low-pressure valve-chests, not in the receivers.

‡ In addition to this, the drain from steam-pipe and high-pressure valve-chest was 0·61 per cent. of the total feed.

the same diagram has been added from Table 18 the carbon-value of the fuel per indicated horse-power per hour.

Steam-Jackets.—None of the two-cylinder compound engines were fitted with jackets; attention is therefore confined to the triple engines for the purpose of comparison. Unfortunately it was not possible to measure separately the steam condensed in the "Meteor" jackets, but only the steam-pressure in the jackets was measured; the wetness of the steam in the cylinders is known therefore only approximately. For the other two steamers the quantity condensed in the jackets is known, and therefore the percentage of total feed so used. The necessary figures are given in Table 30. There are thus only two examples of the high-pressure cylinder jacketed, against one unjacketed or practically so. On calculating from the indicator diagrams the steam present in the high-pressure cylinder just after cut-off, it is found that the percentages of total feed so accounted for are:—"Meteor" 77·1; "Iona" 63·4; "Tartar" 45·2 per cent. In the "Tartar" it is impossible to say how much of the excessive wetness of the steam may have been due to priming, and how much to initial condensation intensified moreover by priming. In the "Iona" the percentage of total feed condensed in the steam-jacket is not high, and may to some extent explain the greater wetness of the steam than in the "Meteor," especially when it is remembered that the "Iona" jacket gave heat not only to the high-pressure cylinder but also to the second receiver.

On examining the percentages of steam present near the end of the stroke in the intermediate cylinder, the results given in the reports appear anomalous. They are:—

Meteor	80·2	per cent.	steam, or	3·1	per cent.	more than	at cut-off	in high-p. cyl.
Tartar	58·2	,,	,,	13·0	,,	,,	,,	,,
Iona	74·9	,,	,,	11·5	,,	,,	,,	,,

The "Iona" having no jacket to her intermediate cylinder, it seems difficult to believe that there has been much re-evaporation in this

cylinder. It has therefore been thought worth while to calculate the percentage of steam present just before release in the high-pressure cylinder, in order to detect whether there was condensation or re-evaporation going on during the stroke in that cylinder. The following are the results of the calculation :—

Tartar	63·9 per cent.	steam at release,	or	18·7 per cent.	more than at	cut-off.
Iona	65·5 ,,	,,	,,	2·1 ,,	,,	,,

These results seem to show slight re-evaporation in the "Iona" during the high-pressure stroke, and a great amount in the "Tartar": which appears extraordinary when it is remembered that the "Iona" high-pressure cylinder was well jacketed, while in the "Tartar" the jacket was practically not in use. In order to test the matter more conclusively, the total weight of steam present in the high-pressure cylinder and clearance has been calculated for two points, one just after cut-off and one just before release. The figures are given in Table 31.

The great re-evaporation in the "Tartar" the author thinks is to be explained only by the assumption of priming (see also pages 72–4); a large quantity of water must have been carried over with the steam, and afterwards evaporated. The difficulty however still remains of explaining where the heat needed for this purpose came from; and at present the author sees no way of accounting for it satisfactorily.

In Table 32 is shown for each steamer the percentage of total feed present as steam in the high-pressure cylinder after cut-off, and before release in this and the other cylinders. The diagram in Plate 10 shows the same percentages graphically, at A after cut-off in the high-pressure cylinder, at B before release in the same cylinder, at C before release in the intermediate cylinder, and at D before release in the low-pressure cylinder.

From these figures it is seen that just after cut-off in the high-pressure cylinder the unjacketed two-cylinder compound engines actually show present as steam a much greater proportion of the total feed than do the jacketed triple engines. As the only explanation which seems at all feasible is that the area of surface

TABLE 31.—*Steam in High-pressure Cylinder (including clearance) at Cut-off and at Release.*

Steamer.	High-pressure Cylinder Jacketed or Not jacketed.	Weight of Steam per rev.		Gain. Per cent. on total feed.
		After Cut-off.	At Release.	
		Lbs.	Lbs.	Per cent.
Fusi Yama . . .	Not jacketed	2·24	2·31	3·0
Colchester . .	Not jacketed	6·77	6·84	0·8
Ville de Douvres .	Not jacketed	27·02	26·36	— 0·2
Iona.	Jacketed	2·26	2·44	7·7
Tartar	Jacket not in use	3·39 †	4·33	18·3

† See also pages 72–4.

TABLE 32.—*Percentage of total feed present as Steam in Cylinders at different points in stroke. See Plate* 10.

Steamer.	High-pressure cylinder.		Intermediate.	Low-pressure.
	After Cut-off.	Before Release.	Before Release.	Before Release.
Two-cyl. Compound.	Per cent.	Per cent.	Per cent.	Per cent.
Fusi Yama . .	N 83·1	N 88·1	—	N 70·8
Colchester . .	N 72·0	N 75·2	—	N 52·7
Ville de Douvres	N 80·6	N 79·3	—	N 72·5
Triple Compound.				
Meteor . . .	J 77·1	J —	J 80·2	J 75·3
Tartar . . .	N 45·2 †	N 63·9	J 58·2 *	J 60·3
Iona	J 63·4	J 65·5	N 74·9	N 59·1

J = Jacketed. N = Not jacketed. * 49·1 at a much earlier point in stroke.

TABLE 33.—*Initial Condensation in High-pressure Cylinder.*

Steamer. High-pressure Cylinder Jacketed or Not.	Feed present as Steam at cut-off.	Range of Temperature in cylinder.	Area of Cooling Surface. *See Plate* 11. Total. Clearance.	Total. Barrel, up to cut-off.	Per pound of entering Steam per stroke. Clearance.	Per pound of entering Steam per stroke. Barrel, up to cut-off.
Triple Compound.	Per cent.	Fahr.	Square Feet.	Square Feet.	Square Feet.	Square Feet.
Meteor, jacketed . . .	77·1	77°	19·30	15·40	5·56	4·45
Iona, jacketed . . .	63·4	81°	* 21·66 *	5·58	19·34	4·98
Tartar, jacket not in use .	45·2	54°	25·40	7·15	9·90	2·79
Two-cylinder Compound.						
NOT jacketed. Fusi Yama . .	83·1	58°	17·30	9·84	14·66	8·34
NOT jacketed. Colchester . .	72·0	73°	45·20	23·54	10·92	5·69
NOT jacketed. Ville de Douvres .	80·6	79°	84·73	47·23	6·05	3·37

In the "Meteor" none of the clearance surface was jacketed, and in the "Iona" only 15 per cent.

* The clearance surfaces in the three cylinders of the "Iona," given in Proceedings 1891 page 222 lines 67–8–9 (and again in 1892 page 163), should be corrected to read as follows:— high-p. cyl. 21·66 sq. ft.; inter. cyl. 36·1 sq. ft.; and low-p. cyl. 64·2 sq. ft.

in the jacketed cylinders must be greater per pound of steam entering per stroke, this has been calculated out, and the results are shown in Table 33; and graphically for the "Meteor" and "Iona" in Plate 11. An inspection of the indicator diagrams, Plate 7, shows that in almost all of them the compression in the high-pressure cylinder was carried up nearly to the initial pressure of the entering steam, except in the "Colchester" where the compression was small. It seems therefore unlikely that the clearance surfaces can have had any great effect in causing condensation of the entering steam; the difference of temperature must have been slight, and the clearance walls must have been almost dry. On the other hand the surface of the cylinder walls is exposed to a considerable range of temperature, namely from the exhaust temperature up to that of the initial steam. It is therefore to be expected that, where this surface was larger per pound of steam admitted per stroke, the condensation would be greater for a given range of temperature. The figures in Table 33 for the "Meteor" and "Iona," both jacketed, show that this expectation is fulfilled pretty closely; the anomalous figures for the "Tartar," when its small surfaces and low range of temperature are considered, can be explained only on the assumption of the enormous influence exerted by the priming water present.

In the non-jacketed engines, no explanation seems satisfactory for the high percentage of steam present in the "Fusi Yama;" judging from the large surface exposed to the entering steam, considerable initial condensation would be expected, while as a matter of fact there appears to have been but little. It is generally found that an engine with large initial condensation is uneconomical, and more so than an engine with small initial condensation; but the figures for the "Meteor" and "Iona" present an apparent discrepancy, their initial condensation being respectively 22·9 and 36·6 per cent., while the steam consumption per horse-power per hour is 14·98 and 13·35 lbs. respectively. The explanation however is most probably to be found in the much larger ratio of expansion adopted in the "Iona," and the consequent partial saving of the loss due to incomplete expansion of steam down to the back-pressure.

Expansion of Steam.—By measurement of the approximate point of cut-off from mean indicator diagrams, the total ratio of expansion has been calculated as follows:—

				Absolute.
Two-cylinder Compound.	Fusi Yama . .	6·1 times.	Boiler pressure	71·64 lbs.
	Colchester . .	6·1 ,,	,, ,,	95·50 lbs.
	Ville de Douvres .	5·7 ,,	,, ,,	120·64 lbs.
Triple Compound.	Meteor . .	10·6 ,,	,, ,,	160·10 lbs.
	Tartar . .	15·7 ,,	,, ,,	158·20 lbs.
	Iona . . .	19·0 ,,	,, ,,	179·58 lbs.

It will be seen that, except in the "Fusi Yama," the two-cylinder compound engines with their late cut-off obtain only a comparatively small ratio of expansion for the boiler pressures at which they work. Since the use of simple valve-gear seems indispensable, owing to the necessity of avoiding complications in the working of such engines, the consumption of steam per horse-power per hour is likely to remain over 20 lbs. in unjacketed engines, contrasting unfavourably with the results obtained in compound engines on land. The great

TABLE 34.

Weight of Machinery, and Indicated Horse-Power.

Steamer.	Weight of Machinery.		Indicated Horse-Power.		Net Volume of Boiler per I.H.P. *See Plate* 12.
	Total.	Per I.H.P.	Total.	Per ton. *See Plate* 12.	
Two-cylinder Compound.	Tons.	Lbs.	I.H.P.	I.H.P.	Cubic Feet.
Fusi Yama . .	100	603	371·3	3·7	4·53
Colchester . .	395	448	1979·7	5·0	2·52
Ville de Douvres	361	272	2977·0	8·2	2·09
Triple Compound.					
Meteor . . .	390·5	439	1994·0	5·1	2·72
Tartar . . .	291	599	1087·4	3·7	4·33
Iona	202	701	645·4	3·2	4·15

expansion obtained in the "Iona" with its high efficiency is a proof of the fact that economy results from such practice. It is in all probability due to this high ratio of expansion that, though a much greater initial condensation is shown in her high-pressure cylinder as compared with the "Meteor," still the consumption of steam is less.

Weight and Horse-Power.—It may be useful to give in Table 34 the actual weight of machinery when in working order, and the horse-power developed. In Plate 12 is shown the indicated horse-power per ton of machinery and per cubic foot of boiler volume.

Circulating Water.—Only in the last two trials made, namely the "Iona" and the "Ville de Douvres," was any regular measurement attempted of the temperatures of the circulating water. [See page 116.] The temperatures of the inlet and the outlet were measured, as well as the hot-well temperature. They were as follows:—

Iona	55·8° inlet and 75·5° outlet = 19·7° rise.
Ville de Douvres .	61·7° inlet and 85·0° outlet = 23·3° rise.

Calculating from the heat contained in the steam at release in the low-pressure cylinder, the quantity of circulating water per pound of steam must have been 52·5 and 43·1 lbs. respectively, with 9·47 and 5·93 square feet of condensing surface respectively per pound of steam per minute. Table 35 (page 70) gives the amount of cooling surface in the surface condensers, and the various temperatures of circulating water and condensed steam.

Conclusions.—A highly important point as to the possible economy of triple compound engines the author considers still remains undecided, namely the influence of thorough jacketing. The ratio of expansion differs so greatly in the "Meteor" and the "Iona" that it is not possible to compare them in regard to jacket influence. What is wanted to determine this point is a pair of consecutive trials on the same set of engines in which all three cylinders are jacketed,

TABLE 35.—*Condensing Surface, and Temperatures of Circulating Water and Condensed Steam.*

Steamer.	Area of Condensing Surface.			Ratio of Heating Surface to Cooling Surface.	Temperature of Circulating Water.			Temperature of Condensed Steam.
	Total.	Per I.H.P.	Per pound of Feed per minute.		Inlet.	Outlet.	Rise.	
Two-cylinder Compound.	Sq. Feet.	Sq. Feet.	Sq. Feet.		Fahr.	Fahr.	Fahr.	Fahr.
Fusi Yama . . .	—	—	—	—	—	—	—	132°
Colchester . . .	3,000	1·52	4·18	1·94	—	—	—	135°
Ville de Douvres .	6,540	2·20	5·93	1·12	61·7°	85·0°	23·3°	160°
Triple Compound.								
Meteor	3,200	1·61	6·43	2·08	—	—	—	138°
Tartar	2,250	2·07	6·26	2·32	*55·0°	89·0°	34·0°	120°
Iona	1,360	2·11	9·47	2·32	55·8°	75·5°	19·7°	90°

* Measurements taken only once or twice during the trial.

one trial with none of the jackets in use, the other with all three in use. If the "Iona" engines had been thoroughly jacketed, still greater economy the author believes would have been obtained, when her great expansion is considered.

One of the chief objects of the Committee was to show that it is perfectly practicable to carry out a complete test of the propelling machinery of a steamer without seriously interfering in any way with the ordinary working; this the author thinks has been decisively proved. Further the trial of the "Ville de Douvres" has shown that by using a meter the measurement of the feed may be made as simply and easily as the weighing of the coal. If indicator diagrams are taken at regular intervals, and fuel and feed measured over a given time, the absolute efficiencies of both boilers and engines are determined with as much accuracy on board ship as on land, though of course as a rule with more discomfort to the observers. The work of the Committee the author therefore trusts will induce shipowners to have systematic tests made of the propelling machinery of their steamers, as is now done on land by millowners and other large users of steam power.

Discussion.

Professor BEARE mentioned that this paper had originally been prepared and announced for the meeting in April of last year; but owing to want of time for the reading and discussion at that meeting it had been deferred until the present meeting. During the interval he had seen reason to modify his views materially with regard to the important question of the behaviour of the "Tartar" during her trial. Originally he had been strongly disposed to reject as untenable the assumption that priming must have taken place to a large extent; and he had considered that some explanation of the perplexity might be found in an unsuspected loss between the feed-tanks and the boilers. The arrangement of the numerous pipes was naturally complicated enough to begin with; and as alterations had to be made for the trial, it seemed possible that by some mischance water might

(Professor Beare.)

have been allowed to escape at some undetected point. Yet if that had been so, the loss must have been found out by examination of the records, which would have revealed the fact that there was an unduly large amount of supplementary feed-water; otherwise the boiler level must have fallen, because the water measured in the feed-tanks was only the condensed steam from the main engines together with the supplementary feed, assuming of course that the condenser was tight. He had therefore examined the records again most carefully, and had found in them nothing whatever to justify the assumption that there was an undue supplementary feed. The only fact he had come across was a solitary note made by Mr. Edwards in one of the log sheets, to the effect that at a certain time in the trial, namely at 8.2 p.m., "the steering engine was now exhausting into the condenser, along with the donkey." This was the only note in the record of the supplementary feed; and it appeared to him that the small quantity of steam condensed from those two engines could not at all make up anything like the large loss he wanted to account for. He had accordingly had to give up the idea that the explanation could be found in loss of water between the feed-tanks and the boilers. Casting about therefore for some other explanation, he had hit upon the idea of calculating from the indicator diagrams the quantity of steam actually present in the cylinders at different points of the stroke. The results of this calculation were given in page 47 and Table 31, from which it would be noticed that there was a much larger quantity of steam present in the high-pressure cylinder just before release than just after cut-off. The increase could have arisen only either from evaporation or rather re-evaporation, or else from leakage past the valve. As the engines had been overhauled immediately before the trial, it seemed inconceivable that so large an amount of leakage could take place past the valve; and he had therefore concluded that the cause must be re-evaporation. It was true that careful calculations of the quantity of heat present at the two points had failed to show where the heat could have come from to account for the supposed re-evaporation. Yet at that time he did not see any other explanation for the increase in the quantity

of steam present. In this connection too he remembered the curious effects he had seen in Mr. Donkin's glass "revealer," in which on admission of steam into the glass cylinder the whole body of it immediately became cloudy, and then as the stroke proceeded in the engine cylinder the cloudiness gradually disappeared from within the glass. While inclining towards this explanation, he was nevertheless doubtful about it, owing to the fact already mentioned that by no calculation could he make out where the heat could come from for this amount of evaporation or of re-evaporation. The calculations of the quantity of steam present at different points of the stroke he had recently verified by repetition, and the results thereby arrived at were illustrated in the indicator diagram, Plate 7. The 3·39 lbs. weight of steam per revolution, mentioned in page 47, was calculated at the point A just after cut-off, and included the clearance volume; this was the point which had been chosen in the original report (1890 page 235) for making the calculation of the steam present in the cylinder. At B, just before release at the end of the stroke, the weight of steam present was 4·33 lbs., being an increase of 0·94 lb. The heat contained in the steam and in the water present in the cylinder at A amounted to 4,580 thermal units per revolution, while at B it had risen to 5,322, showing a gain of 742. Where this gain came from was the puzzle. It did not seem possible that it could have come from the jacket, because ostensibly the jacket was not in use on the high-pressure cylinder; even if it had been, it hardly seemed conceivable that so large a quantity of heat per revolution could have passed from the jacket into the cylinder. The indicator diagram showed that at the point A the pressure of steam in the cylinder was 115·4 lbs. per square inch above the atmosphere. On carefully examining the diagrams it looked very much as if the valve had not really cut off the steam at the point A, notwithstanding that according to the setting of the valve gear the cut-off had already taken place. This conclusion that the cut-off had not really taken place at the point A was confirmed by calculating the quantity of steam present at a point C, a little further down the expansion curve, where it was certain the cut-off must have taken place. Here the quantity of

(Professor Beare.)

steam present was found to be within 8 per cent. of the 4·33 lbs. present at B just before release; and therefore the great bulk of the increase of 0·94 lb. or over 27 per cent. between A and B seemed to have nothing whatever to do with the question of priming or re-evaporation, but to be due simply to the steam continuing to pass into the cylinder after the nominal cut-off, through the valve closing badly and slowly. Considering now the bearing of this view upon the question of priming, the weight of steam present at A in the cylinder proper, after deducting the steam of the clearance space, was 2·32 lbs. per revolution; and adding the increase of 0·94 lb. between A and B, this gave 3·26 lbs. as the weight of steam actually present in the cylinder per revolution at the point B just before release, after deducting that filling the clearance volume. The total feed being 5·13 lbs. per revolution, 3·26 lbs. amounted to 64 per cent. of it: so that there was left for priming and for initial condensation in the cylinder 36 per cent. of the total feed. In Table 32 it would be seen that in the "Iona," where there was some priming certainly, but only to a slight extent, the percentage of total feed present as steam in the high-pressure cylinder was almost identically the same as this, not only just before release but also just after cut-off. Hence he had found himself brought back again face to face with the original perplexity in regard to priming in the "Tartar." That priming must have been taking place seemed certain from the heat account of the boiler; but initial condensation and priming together amounted to only 36 per cent. of the total feed, taking account of the extra steam which must have passed into the cylinder after the nominal point of cut-off had been reached; therefore apparently the initial condensation must have been normal in amount.

Mr. W. H. WHITE, C.B., Member of Council, thought that perhaps some acknowledgment of the value of this paper, and of the work of the Research Committee on whose labours it was based, might come better from one who like himself was engaged in designing steamships, than from those who were engaged in the design and manufacture of their propelling apparatus. It appeared

to him that the work which had been done by the author was of the greatest value to the Institution and to all connected with the use of steam. The preparation of the paper had of course involved dealing with a great mass of facts, and of figures representing supposed facts; and therefore the wonder seemed to him to be, not that there were some difficulties of agreement and interpretation, but that under the circumstances there were not a great many more. The high value of the work done by the Research Committee on marine-engine trials, which had been so well digested and analysed by Professor Beare, appeared to him to lie, not so much in the detailed statements of the performances of the several kinds of engines which had been tested during their working, as in the arrangement of the methods followed, and the description of the observations made, in conducting the trials; these methods would no doubt admit of extensive application and amplification in the future. The Institution he was sure would recognise that there was one gentleman in particular to whom both the organisation of this research and its practical conduct were owing, and that was their new President who had just taken the chair. Remembering what was the condition of the engine-room and stoke-hold under some circumstances at sea, it might well be imagined that neither Professor Kennedy nor those who had assisted him in the trials had always enjoyed themselves afloat; and it seemed possible therefore that some of the difficulties which Professor Beare had encountered in dealing with the figures recorded in the log sheets might be accounted for by temporary absence or incapacity on the part of the observers. But notwithstanding any such possibility, he nevertheless considered that in this extended series of trials, which in the present paper had been digested and analysed in so admirable a manner, the Institution had through the Research Committee rendered a great service to the engineering world. It was not supposed of course that observations made under such conditions as these and over comparatively short periods could be regarded as substitutes for actual experience gained in long-distance steaming at sea. Because such observations did not represent all the conditions of actual service, they were sometimes treated as of little value; but considering the infinite variations in

(Mr. W. H. White.)

the conditions which might occur in actual service, and the inherent difficulties of these questions, all engineers must agree that it was of the greatest service to have some trials made under fairly definite conditions, eliminating circumstances which no doubt affected practical results, but which were not necessarily present, and which had little or nothing to do with the designing of the machinery and boilers in steamships. Exactly the same criticism had been made with regard to steamship speed-trials: the measured-mile trials had been pronounced perfectly useless, because they did not represent sea performance. Nobody supposed that they did; but for purposes of design, everyone who was concerned with steamship construction would know that the measured-mile trials were absolutely necessary, both for determining the approximate power required for the speed in a new ship, and also for ascertaining the relative efficiencies of different forms of propellers. Hence it appeared to him that out of the facts dealt with in the present paper must come beneficial results in future practice, especially if these trials were made models for many others. The recommendation made at the end of the paper, that steamship owners should have the courage to look facts in the face and to make such trials in their own vessels and for their own information, was one that he had no doubt would be adopted and acted upon. The Institution he considered was much indebted to the shipowners who had placed their steamers at the disposal of the Research Committee for these trials; and in considering the results obtained he was sure it would be the feeling of all the members that they must distinguish between scientific analysis of the performances, and any tendency to criticise the results as representing the work of particular firms or the capabilities of particular engines. These trials were suggestive examples, which would not have been obtained at all, had it not been for the courtesy and courage of the owners of these steamers, and of those concerned in the construction of their machinery, in placing them at the disposal of the Institution.

In looking through the paper, what struck him most as a naval architect was that there was no particular kind of engine or of boiler which could be regarded as absolutely the best. There were some

striking examples which showed how for special services the necessary and governing condition was success in the total effort made. The ships had to be considered as built for different services, running over different distances, some of them working with a limited draft of water, and others intended for over-sea voyages at moderate speeds, where economy of coal consumption was of the utmost importance. This consideration of course explained the circumstance that from Table 18 (page 38) it would be found that the area of total heating surface in the boilers ranged from as low as $2\frac{1}{2}$ square feet per indicated horse-power up to more than double that amount; while again from Table 34 (page 68) it would be found that the weight of the machinery—which he understood to include both the engines and the boilers, all in working order—ranged from as much as 700 lbs. per indicated horse-power down to only 272 lbs. Whilst for marine engineers the economy of steam and fuel naturally attracted most attention, yet from the naval architect's and ship-builder's point of view the question of the weight of the propelling apparatus in proportion to the power was the most important, and could not be overlooked. Then again from the engine designer's side it was important to remark in Table 18 that one of the two-cylinder compound engines required 2·90 lbs. of coal per indicated horse-power per hour, while one of the triple-expansion engines took exactly half that amount; and on the other hand from Table 34 it was seen that the weight of machinery per indicated horse-power was only 448 lbs. in the former case, but as much as 700 lbs. in the latter. It was well known that claims were made for remarkable economy in coal consumption in the mercantile marine, as compared for example with war-ships; and there could be no doubt that there was some considerable ground for such claims. It was needless to enter into an explanation of why it was so; it was necessarily so. But on the other hand, in view of such differences as the above—namely between 1·46 lb. per indicated horse-power per hour in the triple-expansion engine and 2·90 lbs. in the two-cylinder compound—it was obvious that there was a good deal more to be taken into account than merely the greater expansion in the triple engine. Formerly he had himself been inclined to be somewhat incredulous as to the claims

(Mr. W. H. White.)

for remarkable economy in merchant ships; but the trials made by the Research Committee had established the fact beyond doubt that the great economy alleged was really attained in some vessels in actual service. In the Royal Navy trials had recently been made which were in their way quite as remarkable. The "Thunderer" with triple-expansion engines ran out to Madeira and home again, developing all the way about 80 per cent. of the power she had attained in the contractor's trial; and her consumption of coal out and home was only about $1\frac{2}{3}$ lb. per indicated horse-power per hour. That was of course a fine result, which did great credit to the makers of the machinery. The "Royal Sovereign" also with triple-expansion engines ran from Plymouth to Gibraltar at a mean speed of 15 knots, with a consumption of 1·84 lb. of coal per indicated horse-power per hour. On the other hand in war-ships working at reduced powers, as they had to do when cruising, the rate of coal consumption increased largely, because here the conditions of working were not fixed and steady as they were in merchant ships.

These were only a few of the many points which had naturally occurred to him in looking through the paper. They might serve to illustrate the interest, which as in some respect an outsider he felt in the subject, and to show his personal sense of obligation to the active members of the Research Committee and to the author of the paper.

Mr. FREDERICK EDWARDS mentioned that in a discussion last year at the Institution of Naval Architects (1893, vol. xxxiv, page 229) he had drawn attention to the circumstance that in the mean indicator diagrams from the "Iona" the steam line in the intermediate cylinder overlapped the exhaust line in the high-pressure cylinder; and he had interpreted this overlapping as showing that these mean diagrams were not really "a true set," meaning thereby that they had not been taken all three at exactly the same moment. Subsequently he had learnt that his meaning had been misunderstood to imply that these diagrams were not reliable. On the contrary, as he had mentioned at the time, he had referred to them because he believed the results obtained from the "Iona" were the most

economical and reliable which had been published. Since then however in regard to this overlapping he had been in communication with Mr. Mudd, who was prepared to offer an explanation which he thought might be of interest to the members. The "Iona" diagrams were so reliable and so well known that he had intentionally selected them for reference, as he thought they were more interesting than any others he could choose.

Mr. Thomas Mudd explained that, in the ordinary way of showing the indicator diagrams from two-cylinder compound or triple-expansion engines, by making the same vertical line serve for the commencement of the stroke in each cylinder, as in Plate 7, the overlapping of the diagrams from the successive cylinders did not involve any suspicion of incongruity. But when the diagrams were placed in their true sequence in point of time, and it was found that they overlapped, the impression at first derived from the overlapping was that the diagrams could not have been taken simultaneously, or, as Mr. Edwards had expressed it, that they were not a true set. There were one or two facts however which appeared to him to offer evidence that the contrary was the case: that is to say, that the overlapping of the diagrams did not necessarily prove that they were not a true set. The first fact was that the diagrams taken from other engines than the "Iona's," when placed in their proper sequence, did frequently overlap, even when the greatest care had been taken to ensure their being a truly simultaneous set. Having been present himself unofficially in the trial of the "Iona," he knew the greatest care had been taken in this case that each set of the indicator diagrams should be simultaneous from the three cylinders; and the indicator springs, as mentioned in the report of the trial (Proceedings 1891 page 211), had all been carefully tested before the trial.

The second fact to which he would call attention was illustrated by Plate 13, where the indicator diagrams from the high-pressure and intermediate cylinders of the "Iona" were placed in their true sequence of time in a straight diagram, and the horizontal length was divided into equal intervals of time or equal arcs in the

(Mr. Thomas Mudd.)

revolution of the crank, instead of into equal parts of the piston-stroke. Here it was seen how, as he had endeavoured to show some years ago in the discussion upon Mr. Wyllie's paper by means of the indicator diagrams from the "Abeona" (Proceedings 1886 pages 511–17, and 1887 pages 47–51), the exhaust line of the high-pressure diagram came down so low that it ran into the steam line of the intermediate diagram, and then quickly rose till it got clear again above the intermediate diagram. The point so naturally raised by Mr. Edwards was, whether this overlapping did not denote some error in the diagrams; or if it did not, how was it to be satisfactorily accounted for. Taking the diagrams to be correct, they plainly showed that at the place of overlapping the receiver pressure was really higher than the exhaust pressure in the high-pressure cylinder, and that just at this time there was a sort of back rush of steam from the receiver into the high-pressure cylinder, clearly indicated at AA in Plate 13, by the hump in the exhaust line or the local rise of pressure in the steam out of its natural curve, soon after release. The diagrams seemed to him to carry on their face sufficient evidence of their truth in this respect; for it was clear that the pressure in the high-pressure cylinder rushed down immediately on release to a pressure below that of the receiver, and then attempted to get back again to the receiver pressure. Of these apparent facts he had only one explanation to offer, to which the Members would give the amount of consideration it might seem to them to deserve. Although, as remarked in the paper (page 55), only the high-pressure cylinder was steam-jacketed in the "Iona," the fact must not be overlooked that the high-pressure steam-chest stood wholly in the intermediate receiver, and therefore to the receiver at all events it formed a good steam-jacket, although situated inside the receiver instead of outside. The steam exhausting from the high-pressure cylinder into the intermediate cylinder rushed all round the high-pressure steam-chest on its way, and must thereby abstract some heat from the boiler steam in the high-pressure steam-chest, which thus acted as a re-heater to the steam in the receiver. Perhaps this fact might explain also something else that had been difficult to understand

hitherto: namely the cause of what had been regarded as the high initial condensation in the high-pressure cylinder of the "Iona," which was represented by something like 36 per cent. of the total feed present as water in the high-pressure cylinder at the point of cut-off, although there was practically no priming that could be detected. There was however this fact to be borne in mind: that, although the steam going from the boiler into the high-pressure steam-chest showed no presence of intermixed water, it was going into a steam-chest which was enclosed within the intermediate receiver, and which was therefore losing heat all round, with consequent formation of moisture in the steam contained in the steam-chest. A large proportion of the water found in the high-pressure cylinder at the point of cut-off he therefore thought could not be truly regarded as due to initial condensation in the cylinder, that is, as water resulting from condensation of what had been dry steam at the moment it entered the cylinder; but it was like priming water, or moisture contained in the steam before it entered the cylinder, and was caused by the high-pressure steam-chest giving up heat to the intermediate receiver, and producing the very effect of overlapping which was seen in the indicator diagrams. These facts therefore seemed to account for the wetness of the steam in the high-pressure cylinder and its dryness in the intermediate, in spite of the circumstance that nominally the high-pressure cylinder was jacketed and the intermediate not jacketed.

In the heat balance-sheet given in Table 18, page 39, there seemed to him to be needed some slight modification in the division of the loss, so far as regarded the temperature of the funnel gases in the "Iona." For practical reasons the temperature had in that case been taken rather high up the funnel, at a point 30 feet above the fire-grate, as mentioned in page 50; and the loss of heat given in the balance-sheet was the heat carried away from the boilers by the funnel gases on the assumption that the gases were escaping at the temperature measured at that high point. Obviously however the loss began much lower down; as soon as ever the gases escaped from the boiler tubes into the smoke-box they were done with for all

(Mr. Thomas Mudd.)

practical purposes in the boiler. In the Chief Engineer's subsequent trial (Proceedings 1891, pages 217 and 222) the temperature had been taken in the smoke-box in front of the tubes, with the result that it had been found to be some 220° higher than in the Research Committee's trial. Consequently the thermal loss in the funnel gases, instead of being only 16·2 per cent. as given in Table 18, would be something like 24 per cent.; and instead of there being 13 per cent. loss unaccounted for—which the author had assumed (page 51) to be due in the main to radiation, owing to the large size of the boilers in the "Iona" (page 52)—the loss unaccounted for wanted considerably reducing, to correspond with the considerable increase in the heat actually escaping up the funnel.

Capt. H. Riall Sankey noticed that in pages 63–4 of the paper there were some interesting calculations with regard to the percentage of steam present in the several cylinders at different points of the stroke; and some further information on this subject had also been given by the author (pages 72–4). This and other matters could be conveniently exhibited in a graphic form by transferring the ordinary indicator diagram, that is the *pv* or pressure-volume diagram, on to the well known theta-phi or temperature-entropy chart * worked out by Mr. Macfarlane Gray; and he wished to show how this could be done by a method which he had himself employed for some time past, but which he had only lately succeeded in perfecting. In this way he hoped also it might be possible to throw some light upon the difficulty dwelt upon by Professor Beare, as regarded the excessive amount of water present in the high-pressure cylinder of the "Tartar."

* To avoid confusion, it is proposed to reserve the term $\theta\ \phi$ *diagram* for the diagram transferred from the indicator diagram: thus the high-pressure $\theta\ \phi$ diagram, the intermediate $\theta\ \phi$ diagram, and the low-pressure $\theta\ \phi$ diagram will be appropriate terms corresponding with the respective indicator diagrams. What has hitherto been generally known as the $\theta\ \phi$ diagram it is proposed to call the $\theta\ \phi$ *chart*, Mr. Macfarlane Gray having originally described it as a heat chart (Proceedings 1889, pages 412–413).

The method * he now referred to required that a series of curves representing constant volumes should first be drawn upon the θ ϕ chart, representing successive volumes in cubic feet, as shown in Fig. 17, Plate 14; and also lines of constant pressure, which for steam not superheated were horizontal straight lines, because they coincided of course with the corresponding horizontal temperature lines drawn from the equally divided vertical scale of temperature. In Plate 14 the numbers placed along the steam saturation curve SS showed the cubic feet occupied by one pound weight of saturated steam at various pressures and corresponding temperatures: for instance, at approximately 150 lbs. absolute pressure per square inch the volume of one pound of steam was 3 cubic feet; and following this particular curve of constant volume to the point C, it would be seen that, when only one-half of the pound of H_2O† had been evaporated, the other half still remaining water, the pressure was about 70 lbs. Similarly the volume, pressure, and temperature of that portion of the pound of H_2O which was steam could be read off from the θ ϕ chart for any point whatever within the limits of the chart. The construction of the θ ϕ chart, it would also be remembered, was such that the distance measured horizontally from any point P in Plate 14 to the saturation curve SS represented the proportion by weight still remaining water in the pound of H_2O; and the horizontal distance from the same point P to the water curve W W represented the proportion present as steam. In other words the ratio of the length W P to the total length W S across the chart was the dryness fraction of the steam at the point P.

The first step towards transferring the indicator diagram to the θ ϕ chart was to obtain, by the ordinary method of calculation, the dryness fraction at some point p in the expansion of the steam, Fig. 18, Plate 15. The point p should be chosen sufficiently beyond the cut-off to ensure that the valve was completely closed, so that no

* In compliance with Mr. Cowper's subsequent request (page 109), the description of the mode of transferring the indicator diagram on to the θ ϕ chart has here been amplified.

† It is proposed to use the chemical symbol H_2O to denote the substance when it is present partly as water and partly as steam.

(Capt. H. Riall Sankey.)
more steam could enter the cylinder. The absolute pressure having been measured at the point p on the indicator diagram, and the dryness fraction having been obtained, the corresponding point P of the θ ϕ diagram, Fig. 19, could then evidently be plotted on the chart. The volume at the point P was then found by interpolation from the constant-volume curves; in the present example it was 3·8 cubic feet. The actual volume in the cylinder, including the clearance, was then determined from the dimensions of the engine for the point p, Fig. 18, namely 69 cubic feet; and the ratio of these two volumes gave a volume factor of 18·16, by which to divide the actual cylinder-volumes on the indicator diagram in order to obtain the volumes on the θ ϕ diagram. In other words the weight of H_2O in the cylinder and clearance of the actual engine was 18·16 lbs., instead of only 1 lb. as taken on the θ ϕ diagram.

The next step was to measure the volume and absolute pressure for a number of points on the indicator diagram; the volumes were then divided by the volume factor, and the points could then be transferred to the θ ϕ chart; on joining them the θ ϕ diagram corresponding with the indicator diagram was obtained. As above mentioned, the starting point p should be chosen after cut-off; but in some cases the indicator diagram did not show the point of cut-off clearly, and the point selected might then happen to be before cut-off had taken place. In such a case the error would become apparent on plotting the θ ϕ diagram; and moreover the correct point of cut-off would be shown, so that a fresh start could be made with a new point p. The area of the θ ϕ diagram multiplied by the volume factor and by Joule's equivalent was of course equal to the area of the pv or indicator diagram expressed in foot-pounds; and this could be used as a check on the accuracy of the work. [See also pages 132–3.]

In this manner the mean indicator diagrams of the "Ville de Douvres," the "Iona," and the "Tartar" had been transferred to the θ ϕ chart, as shown in Plates 15, 16, and 17; the measurements had been taken from the mean indicator diagrams published in the Proceedings, namely:—"Ville de Douvres" 1892, Plate 15; "Iona" 1891, Plate 47; "Tartar" 1890, Plate 100. Referring to Fig. 19,

Plate 15, for the "Ville de Douvres," it would be seen that AB on the $\theta\ \phi$ diagram corresponded with the admission line *ab* on the indicator diagram, Fig. 18; BC with the expansion curve *bc*; CD with the release *cd*; DE with the exhaust *de*; and finally EA with the compression curve *ea*, and with that part of the admission which took place at practically constant volume, when the crank was passing the centre. For further enabling the comparison of the two kinds of diagrams to be readily made, the percentages of the stroke had also been marked at a few points on the $\theta\ \phi$ diagrams; thus in Fig. 19, at A zero, at B 62 per cent., and at D 100. [See also page 130.]

As already explained, the position of a point on the $\theta\ \phi$ chart determined the proportion of water and steam present in one pound of H_2O; and this law would hold good for every point of the $\theta\ \phi$ diagrams just described, if the changes in the cylinder were produced by the alternate applications of a hot and of a cold body, as described by Rankine. But in an actual engine these changes were brought about by the alternate admission and exhaust of steam: so that in its entirety the law evidently held good only for the expansion part of the stroke, that is, whilst the cylinder was closed and contained one pound of H_2O. For all other points on the diagrams the chart showed only the volume of steam present in the cylinder; and no conclusion could be drawn as to the quantity of water present. It followed that the position of the point of cut-off B on the $\theta\ \phi$ chart, Plate 15, enabled the proportion of water in the cylinder at that point in the stroke to be determined. If there were no priming, leakage, conduction, or radiation, the whole of this water would be due solely to initial condensation; that is to say, it must originally have entered the cylinder as steam, which had afterwards been condensed in the cylinder; and all the heat in the steam from which it had been condensed would of necessity be stored in the cylinder walls &c. and in the water present in the cylinder. If during expansion the whole of this heat could be recovered, the expansion line of the $\theta\ \phi$ diagram would follow the dotted line BR, which was found by the method explained in Mr. Willans' paper on steam-engine trials, read before the Institution of Civil Engineers

(Capt. H. Riall Sankey.)

in April 1893 (Proceedings vol. cxiv, page 36). On the other hand, if the whole of the water shown to be present in the cylinder at cut-off had come into it originally as water at the temperature of the point B, namely 325°—that is, had not been produced by condensation during admission, and therefore had not parted with heat to the cylinder walls &c.—the heat-recovery possible during expansion would evidently be far less, and would be shown by the dotted line Br. The point r could be obtained as follows. The vertical strip of the breadth mn, extending down to absolute zero and including the triangle mWn, represented the heat given to one pound of water in raising it from the exhaust temperature near D to the cut-off temperature at B. If mn were divided at x in the ratio BS to BW, the vertical strip of the breadth xn, together with the triangle xWn, would pretty closely represent the heat which, during the same rise of temperature, would be given to the priming water present at cut-off. Hence a similar vertical strip, in which the breadth lr was equal to xn, would represent the heat given out to the steam by the priming water in cooling from the cut-off temperature to the release temperature. The two dotted lines BR and Br might be called the lines of condensation-water heat-recovery and of priming-water heat-recovery respectively. Evidently therefore the expansion curve of an actual engine ought to lie somewhere between these two extreme lines, provided that during expansion no heat was either introduced into the cylinder or taken out of it; and thus the position of the actual expansion curve in relation to these two extreme limits would give valuable information as to what was going on in the cylinder during expansion. It was possible to show the θ ϕ diagram which an ideal engine would produce, if working perfectly within the limits of the conditions imposed upon the actual engine; and the same might be done for each cylinder separately: this was a question he was still investigating. In this connection it was necessary to guard against a possible misunderstanding which might arise. When showing the thermal losses of an actual engine in comparison with a theoretical engine working within the same range of temperature, Mr. Willans had preferred not to show the clearance steam; and in that case the area of the θ ϕ diagrams gave

the thermal efficiency of the actual engine by direct comparison with the heat units utilised by the theoretical engine. In the present enquiry however the clearance steam was shown; and consequently the areas of the $\theta\ \phi$ diagrams did not directly give the thermal efficiency, but had first to be multiplied by the ratio of the volume of the total steam at cut-off to that of the working steam. This was a disadvantage which arose from showing the clearance steam; but on the whole he was at present of opinion that it was better to include it, at any rate for the purposes now under consideration.

In the high-pressure $\theta\ \phi$ diagram for the "Ville de Douvres," Fig. 19, Plate 15, it would be observed that the expansion curve BC, falling away as it did to the left of the priming-water heat-recovery line B*r*, showed a distinct loss of heat from the cylinder during the expansion. The loss was easily accounted for by the fact that, as pointed out in the paper (page 53), the high-pressure cylinder was surrounded by the receiver; and therefore heat was flowing out from the hotter steam in the cylinder into the cooler steam in the receiver, and the flow would be much facilitated by the cylinder walls being no doubt wet both inside and out. It would also be noticed that there was a considerable loss from incomplete expansion in this cylinder, due to the release at C taking place too soon, thereby cutting a piece off the toe of the indicator diagram, Fig. 18, and also off the $\theta\ \phi$ diagram, Fig. 19; but the amount of the loss was more clearly shown on the $\theta\ \phi$ diagram. The loss could evidently have been obviated by making the cut-off in the low-pressure cylinder somewhat earlier, so as to get rather a higher pressure in the receiver, and thereby raise the back-pressure curve of the high-pressure cylinder. The loss from incomplete expansion in the low-pressure cylinder, as well as from bad vacuum, was also evident.

In the $\theta\ \phi$ diagrams of the "Iona," Plate 16, the difference between the expansion curves in the high-pressure and low-pressure cylinders was very marked, and was no doubt due to the former being jacketed and the latter not. In the high-pressure cylinder the expansion curve came fairly close to the line BR of condensation-water heat-recovery. But on turning to the

(Capt. H. Riall Sankey.)
intermediate cylinder, which was not jacketed, it was seen that, instead of the expansion curve falling further away, as it might have been expected to do, it actually went slightly beyond the condensation-water heat-recovery line. This could take place only as the consequence of heat having come into the cylinder in some unusual way after cut-off; and in this case he thought it might possibly be due to leakage of steam through the valve. It was true that, owing to the construction of the engine, the steam was reheated in the receiver: the effect of which was clearly shown in the $\theta\ \phi$ diagram by the admission line of the intermediate cylinder being at a higher temperature than the exhaust line of the high-pressure cylinder, but more particularly by the marked increase in the dryness fraction at cut-off in the intermediate cylinder; this however in no way accounted for the heat received after cut-off. The idea that this effect was due to a leaky valve received confirmation from the fact that when, instead of plotting the expansion curve shown by the full line in Plate 16 from the mean indicator diagram of the intermediate cylinder, the two indicator diagrams for the top and bottom of the cylinder were plotted separately, the form of the expansion curve b for the bottom was such as might be expected for a non-jacketed cylinder, as would be seen by comparing it with the expansion curve for the non-jacketed low-pressure cylinder, plotted from the mean indicator diagram; but the expansion curve t for the top went so far beyond the condensation-water heat-recovery line that it appeared to him to denote clearly a leakage at the valve admitting steam into the top of the cylinder. The $\theta\ \phi$ diagram for the low-pressure cylinder showed the advantage derived from a good vacuum; if the vacuum had been the same as in the "Tartar," for instance, the portion of the low-pressure $\theta\ \phi$ diagram below the line MN would have been lost.

The $\theta\ \phi$ diagrams had also been made out for the "Tartar" in Plate 17. In the diagram for the high-pressure cylinder he thought the points dwelt upon by Professor Beare were pretty clearly brought out in a graphic form, and his conclusions confirmed. The actual re-evaporation in this cylinder, instead of being so considerable

as would appear from the figures given in the report of the trial before they had been corrected by the author, was seen from the θ ϕ diagram to have been really small. The reason for the difference was that given by Professor Beare (page 73), that the point assumed as the point of cut-off was too early in the stroke. What might be called the mechanical cut-off might have occurred at about one-third of the stroke; and from this point to half stroke the admission line on the θ ϕ diagram showed considerable wire-drawing, due probably to the valve closing too slowly, so that the steam was really cut off only at about half stroke. It would be noticed on the indicator diagram that the wire-drawing was so considerable as to make this part of the admission line look like the beginning of the expansion curve; the θ ϕ diagram however discriminated between the two. That the valve did not merely leak was distinctly shown by the fact that the expansion curve did not project much beyond the priming-water heat-recovery line; whereas, if there had been a leakage of steam going on continuously, the expansion curve would have been found to bulge outwards from the first, much in the same way that it was observed to do in the θ ϕ diagram for the intermediate cylinder of the "Iona," Plate 16. The dryness fraction of the steam at half stroke, which appeared to be about the true cut-off, was 59·1 per cent. as obtained from the θ ϕ diagram, instead of 45·2 per cent. as given in the report (1890 page 235). This went a long way towards explaining the great discrepancy between the feed and the steam as shown by the indicator; but it did not account for the apparently excessive evaporation of the boilers, which he thought could be explained only on the supposition that unevaporated water was bodily ejected from the boilers. As a possible cause he would suggest that the oscillation of the water in the boilers might have synchronised with the rolling of the ship, and thus have led to violent commotion of the water in the boilers. The dryness fraction of the steam as it issued from the boiler, calculated on the assumption that the boiler efficiency was 68 per cent., came out as low as 75 per cent., or 25 per cent. priming; on the assumption that the boiler efficiency was as high as 75 per cent., the dryness fraction would be increased to

(Capt. H. Riall Sankey.)

82 per cent., and the priming reduced to 18 per cent.* The lower dryness fraction of 75 per cent. did not appear unlikely, and was plotted on the $\theta\ \phi$ chart at the point Y, Plate 17, so that YS represented the water coming as water from the boiler. The remainder BY of the water shown at cut-off was therefore due to initial condensation, and on measurement turned out to be 21 per cent. of the steam WY coming into the cylinder: quite a reasonable percentage for the range of temperature and the speed of revolution. The true theoretical heat-recovery line, being due partly to priming water and partly to initial condensation, would therefore lie somewhere between the two extreme heat-recovery lines, as shown by the intermediate dotted line BH; and the difference between this line and the expansion curve was a measure of the loss due to conduction, radiation, and leakage. Coming to the intermediate and low-pressure cylinders, the effect of their steam-jackets was immediately seen in Plate 17; their expansion curves followed somewhat closely the condensation-water heat-recovery line. It was noticeable however that the dryness fraction was nearly constant throughout all three diagrams in Plate 17, showing that no material improvement had been effected in the quality of the steam by the jacketing of the intermediate and low-pressure cylinders: the high-pressure cylinder had done badly, and the other two followed suit, their jackets being unable to cope with the large quantity of water coming from the first cylinder. The curve FF of equal dryness-fraction had been drawn through the half-stroke cut-off in the high-pressure cylinder, and it was thereby seen that the quality of the steam continued practically the same, both at the 40 per cent. cut-off in the intermediate cylinder and at the half-stroke cut-off in the low-pressure.

In regard to the increased horse-power which, as shown in Table 28, would have been obtained in the low-pressure cylinder, had its back-pressure been the same as that of the condenser, it was stated in page 59 that this increase would have been brought about without

* In compliance with Professor Beare's subsequent request (page 124) these percentages have been re-calculated, and are found to be correct for the boiler efficiencies assumed.

the expenditure of any more steam. This statement he thought required a little qualification, because a reduction in the back-pressure caused an increase in the range of temperature in the cylinders, and thereby increased the initial condensation: so that really more steam would be required in order to obtain the increase in horse-power. This was clearly seen from the $\theta\ \phi$ diagram of the "Ville de Douvres," Plate 15, because, had the back-pressure in the low-pressure cylinder been the same as in the condenser, the low-pressure diagram would have been increased by the dotted portion shown in Plate 15, equivalent to 132 horse-power, as given in Table 28; but the total range of temperature in the engine would have been increased by $10\frac{1}{2}°$, which would have produced slightly greater initial condensation, and would thus have reduced the area of both the high-pressure and the low-pressure $\theta\ \phi$ diagram. These losses however would have been less than the gain.

Again in page 69 it was said that the great expansion obtained in the "Iona" with its high efficiency was a proof of the fact that economy resulted from such practice. The economy here spoken of he thought should be defined as economy in feed-water per indicated horse-power; for it did not necessarily follow that economy per brake horse-power would result. Turning to Table 34, the indicated horse-power obtained per ton of the machinery rather pointed to this distinction; for in the "Iona" the indicated horse-power obtained per ton was no more than 3·2, whereas in the "Ville de Douvres" it was as much as 8·2: showing that the greater expansion required a much larger engine, which meant increased engine-friction. [See also page 130.]

Mr. JOHN PHILLIPS asked how far Mr. Mudd's view (page 81) respecting the loss of heat in the funnel gases would be modified by the position of the damper at a height of 17 ft. 8 ins. above the fire-grate in the "Iona," and by the effect of forced draught producing a plenum of pressure below the damper and a vacuum above it.

Mr. MUDD replied that he had been dealing with the point at which the temperature of the funnel gases had been taken in the

(Mr. Thomas Mudd.)

Committee's trial, namely 30 feet above the fire-grate. That was considerably higher up in the funnel than the damper. The position of the damper and the use of forced draught he thought did not affect what he had tried to bring out, namely that the temperature of the gases escaping from the boiler tubes must have been much higher than it was at the point where it had been measured in the trial.

In Capt. Sankey's remarks (page 88) it seemed to have been assumed that the intermediate valve of the "Iona" must have been leaking steam, because there was an accession of heat that could not otherwise be accounted for. In the explanation however which he had already offered (pages 80–81) he had endeavoured to make it clear that, whilst there was leakage of heat, if it might so be called, there was no leakage of steam: that is, at the time the steam was going into the intermediate cylinder it was receiving an accession of heat direct from the boiler through the walls of the high-pressure steam-chest.

Mr. Jeremiah Head, Past-President, noticed that, while the series of marine-engine trials which had been made at the cost and on the initiative of the Institution had in the present interesting and able paper been put into a condensed, and to a considerable extent a useful and systematic form, the paper still consisted of a record of a large number of interesting facts, upon which opinions had been somewhat charily expressed by the author, probably for the reason that it was desired to elicit the opinions of the members, who might be more likely to consider what these facts might lead to, if they had not a set of opinions placed before them ready cut and dried. In view of so many interesting tables and of the facts recorded in them, a few ideas and suggestions could not fail to occur to him, although they might perhaps be of a rather crude nature, because it required a long time to assimilate such a large mass of experimental facts and draw any conclusions from them. Confining himself however to the last two trials, namely those of the "Iona" and the "Ville de Douvres," a comparison he thought might advantageously be drawn between these, because they seemed to him to typify two leading classes of steam vessels in this country. Thus the "Iona" was an

excellent example of a cargo vessel, a class which was sometimes looked down upon by those who stigmatised them as "ocean tramps." The "Ville de Douvres" was a type of vessel of much finer lines, which was intended to go at a very high speed indeed, and to carry only passengers and mails.

In comparing these two steamers it would be seen from Table 16 that the displacement of the "Iona" was four times that of the "Ville de Douvres." If too the immersed midship section were considered, that is, the breadth multiplied by the draft, it would be found that the "Iona" had just three times the immersed midship section of the "Ville de Douvres," although four times the displacement. This showed at once that the "Iona" could not have had anything like such fine lines as the "Ville de Douvres": indeed the speed of the "Iona" was just half that of the "Ville de Douvres." The indicated horse-power which drove the four-fold tonnage of the "Iona" through the water was in the ratio of 1 to $4\frac{1}{2}$ in comparison with the power in the "Ville de Douvres," Table 27; or taking the indicated horse-power (Table 27) per ton of displacement (Table 16), it would be found that the "Iona" had only 1-7th of a horse-power per ton, while the "Ville de Douvres" had $2\frac{3}{4}$ horse-power. Hence the "Ville de Douvres" had 18·7 times the power of the "Iona" per ton of displacement, and her higher power propelled her at only twice the speed. The relation however between the indicated horse-power and the tons of displacement seemed to vary largely; and it was a most interesting relation indeed, because it showed the great cost at which high speeds were attained. Turning for instance to a few other well-known vessels apart from those dealt with in the paper, it would be found that the "Teutonic," which went at 21 knots per hour, had a little more than 1 I.HP. per ton of displacement; the "Campania," which went at $21\frac{1}{2}$ knots per hour, had 1·6 I.HP. per ton of displacement; the Argentine cruiser called the "Ninth of July," built by Armstrong, Mitchell and Co., which made 22 knots per hour, had 4·1 I.HP. per ton of displacement; the torpedo boat "Ariete," built by Thornycroft, which went at 26·18 knots per hour, had 14 I.HP. per ton of displacement; and the last effort in that line, the "Havoc," which

(Mr. Jeremiah Head.)
on its trial went at 26·89 knots per hour, had 17 I.HP. per ton of displacement. The range from the cargo steamer "Iona," which had only 1-7th of a horse-power per ton of displacement, up to the "Havoc," which had 17, was 1 to 119, which was indeed extraordinarily wide.

The cargo boats or ocean tramps, as he had already intimated, had been somewhat looked down upon as scarcely examples of the highest kind of marine engineering. Nevertheless in the way of economy they had realised some wonderful performances, of which in one or two instances he happened to know the particulars. The screw-steamer "Westoe," built at Hartlepool, which carried 3,500 tons dead weight at 9 knots per hour, used only 0·64 oz. or two-thirds of an ounce of coal per ton per knot, at the cost of 1-500th of a penny. The "Oscar II.," a rather larger cargo boat also built at Hartlepool, which carried 4,600 tons dead weight on 14 tons of coal per day of 24 hours at 9 knots per hour, used exactly 0·50 oz. or only half an ounce per ton per knot. Another boat rather larger still, the "Aldworth," which carried 5,000 tons dead weight on 15 tons of coal per day at 8·9 knots per hour, did it also on 0·50 oz. or half an ounce per ton per knot. Therefore it seemed this was rather a convenient figure to remember, that produce could be taken across the ocean in such vessels with a consumption of only half an ounce of coal per ton per knot.

Looking next at the boilers and fuel, the coal used by the "Iona" seemed from Table 19 to have had 3 per cent. more heating power in it than that used by the "Ville de Douvres"; while from Table 18, in respect of the evaporation per lb. of carbon-value of the coal, which was the test of the boiler efficiency, still the boilers of the "Iona" were 5 per cent. better than those of the "Ville de Douvres." From Table 34 the indicated horse-power per cubic foot of boiler volume in the "Iona" as compared with the "Ville de Douvres" was as nearly as possible as 1 to 2; that is, the boilers of the "Iona" were only half as hard worked, or in other words the "Iona" had ample boiler-power. The higher steam-pressure in the "Iona" was of course one of the things that gave her an advantage; from Table 26 her boiler pressure (absolute) was 49 per cent. higher than

in the "Ville de Douvres," being 180 lbs. per square inch as compared with 121, thereby enabling a much greater expansion to be realised.

From the heat balance-sheet in Table 18 it would be noticed that, while in the "Iona" 69·2 per cent. of the thermal units went into the feed-water as against only 66·1 in the "Ville de Douvres," on the other hand only 16·2 per cent. of the thermal units went to waste in the funnel gases as against 26·8 per cent. in the "Ville de Douvres": showing that in the "Iona" more heat went into the feed-water and less into the funnel gases. Again in the "Iona" only 1·6 per cent. of the thermal units was lost in unburnt carbon in the ashes, and double that amount in the "Ville de Douvres": showing that in the latter somehow or other more coal was let fall through the grate, probably by forcing the fires. Nevertheless the thermal units unaccounted for in the "Iona" were as much as 13 per cent. of the whole, and only 4 per cent. in the "Ville de Douvres." Professor Beare's idea he thought was that this was owing to the larger proportionate surface of boiler and the consequent larger loss by radiation in the "Iona." Yet, if this theory was correct, the conditions and the evaporation of the steam were notwithstanding altogether better in the "Iona" than in the "Ville de Douvres."

There was one rather peculiar circumstance about the amount of air that was used for the combustion of the fuel. It must have occurred to many others besides himself that when forced draught was used with marine boilers it might be expected that a great deal more air would be forced through the furnaces and wasted, than with the natural chimney draught, with which latter the air was allowed more to take its own time, as it were, in uniting with the fuel. The trials of the "Iona" and the "Ville de Douvres" were both made with forced draught, and all the other four trials were with natural or chimney draught. The air pressure with the forced draught in the "Iona" was 0·86 inch of water (page 36), and in the "Ville de Douvres" from 0·7 to 1·0 or say an average of 0·85 inch, being thus practically the same in each steamer. In the chimney however the "Iona" had a draught of only a quarter of an inch of water (Table 22), while the "Ville

(Mr. Jeremiah Head.)
de Douvres" had more than one inch; but the latter he presumed was owing both to the much greater heat going to waste in the chimney of the "Ville de Douvres," and also perhaps to the smaller tubes causing more obstruction to the passage of the gases through them. Turning now to the weight of dry air actually used per lb. of fuel, the average of the four steamers that had only chimney draught was found from Table 22 to be 21·5 lbs. of dry air; and though it would be expected that there would be more in the "Iona" and the "Ville de Douvres" with their forced draught, nevertheless the average of these two was only 21·2 lbs. This seemed to show that there was not any greater excess of air passing through the furnaces under the influence of the forced draught than with the natural or chimney draught. Looking also at the analysis of the gases in Table 22, and taking first the nitrogen—which he considered fairly represented the air, because this gas alone went through the furnace uncombined, and therefore unaltered in quantity, and whether the oxygen came out mixed with it or combined with the carbon as carbonic acid did not much matter; the nitrogen was there all the same, and therefore the weight of nitrogen in the funnel gases must truly represent the weight of air going through—it was found that the average of the nitrogen in the first four steamers with their chimney draught was 75·78 per cent.; while in the last two with their forced draught it was 75·29 per cent., or rather less than in the others. This confirmed the conclusion arrived at from the weight of dry air. Not only so, but in respect also of the oxygen it would be found that in the first four the average was 10·79 per cent., while in the "Iona" and the "Ville de Douvres" the average was 10·22 per cent.; that is, there was rather less oxygen with the forced draught than with the chimney draught, just as there was rather less nitrogen. Therefore it might be taken as evident that there was rather less air altogether with the forced draught. Looking at the carbonic acid in the funnel gases, the average of the four steamers with chimney draught was 13·23 per cent., and of the two with forced draught 14·48 per cent. This seemed to him to be in favour of the forced draught, as showing that there had been more perfect combustion. Therefore on the whole the conclusion

appeared to him to be that the forced draught neither allowed more air to pass through the furnace nor permitted of more imperfect combustion; but that really the combustion was rather better and on rather less air than when the forced draught was not used.

With regard to the total weight of machinery, to which attention had already been drawn by Mr. White (page 77), it would be seen from Table 34 that the "Iona" gave 3·2 indicated horse-power per ton and the "Ville de Douvres" 8·2, showing that the "Iona's" engines were as much as 2·56 times heavier than those of the "Ville de Douvres." At the same time the ratio of expansion in the "Iona" was 19·0 times, and in the "Ville de Douvres" 5·7; that is, 3·33 times as much in the former as in the latter. Therefore if a high degree of expansion were wanted, it must be expected that rather big and heavy engines would be needed. The feed-water per indicated horse-power per hour (Table 29) was in the proportion of 100 in the "Iona" to 155 in the "Ville de Douvres"; that is, it was 55 per cent. more in the latter. From Table 29 also the efficiency of the engines corresponded very nearly with what was arrived at from the fuel consumption in Table 18: it was as 146 to 100 in favour of the "Iona," while the carbon-value of the fuel consumption per indicated horse-power per hour was as 100 in the "Iona" to 159 in the "Ville de Douvres."

The results of these trials, and the attention which had been given to them, the time they had occupied, and the energy that had been bestowed upon them, would constitute he hoped a kind of epoch in marine engineering. In this country so much depended on the efficiency of our steamers — even our very food supplies — that anything which could be done in the way of increasing their efficiency was like increasing our daily bread in more ways than one: not only in bringing food cheaply across the seas, but also in enabling this country, in the building of ships and engines, to keep the lead which it had so long enjoyed, which it still held, and which he trusted it would always continue to hold. The simple apparatus which had been described, wherewith these trials had been carried out, and the ease with which it was applied, would he hoped encourage shipowners, wherever they could do so, to keep it always on board, so that the

(Mr. Jeremiah Head.)
engineers could try their engines in as thorough and systematic a way as possible, not only at the beginning of a voyage, but also during its course and at the end, so as to see whether there was any deterioration in their working; and if any such statistics so gathered were forwarded for record to one place, as for instance to this Institution, they would he was sure be of the greatest possible value.

In connection with the extraordinary variation of 1 to 119, which he had shown (page 94) to exist in the amount of power put into steamers per ton of displacement, the question naturally arose whether so remarkably small an amount of power as that in some cargo ships, going down to as low as one-seventh of an indicated horse-power per ton of displacement, was really enough under the trying circumstances which sometimes arose at sea. Within two months past there had been at least one terrible storm, causing a considerable number of cargo boats to be lost, and nobody knew exactly in what way they had been lost. When however the story was remembered of the hurricane which took place at Samoa five years ago, wherein the cruiser "Calliope" with her strong and excellent engines of enormous power was the only steamer which was able to go against the storm and to make her way out to sea in safety, the other vessels in the harbour being all driven ashore and lost; when the enormous power was borne in mind which had to be exerted in that ship to steam against the hurricane; and when the number of cargo vessels was contemplated which in heavy weather had been lost and never heard of again:—he could not help suspecting that shipbuilders and marine engineers might perhaps have gone almost too far in keeping down the power in those vessels, and it no doubt behoved them to consider this matter seriously. It was not enough he considered that goods should be carried across the sea at such exceedingly economical rates as he had shown (page 94) had now been attained, if the whole vessel was liable to be wrecked, and the lives it carried to be lost, in the event of one of the furious gales which occurred every now and then. Even at the sacrifice of some expense in the transit of goods, there ought to be sufficient power he thought on board every ship to be able to bring her safely to port, whatever happened.

Mr. ALFRED SAXON thought that, from a land engineer's point of view, if all marine engines had as much reserve power stored up in them as had the engines of the "Iona" at the time when the indicator diagrams were taken in the trial, no fear need be felt for the safety of cargo steamers as far as power was concerned. It was shown in Table 26 that the "Iona" with a boiler pressure of 179·58 lbs. absolute per square inch had been developing a mean effective pressure referred to the low-pressure cylinder of only 21·13 lbs. per square inch, whereas the "Ville de Douvres" with a lower boiler pressure of only 120·64 lbs. had been developing as much as 30·17 lbs. The triple-expansion engines in the "Meteor," which might also be taken for comparison with those in the "Iona," had been doing practically the same effective work as the engines in the "Ville de Douvres," their mean effective pressure referred to the low-pressure cylinder being 29·90 lbs., while that in the "Ville de Douvres" was 30·17 lbs. It was therefore seen that in the triple-expansion engines of the "Iona" there was a considerable reserve of power before reaching these higher effective pressures in the low-pressure cylinder: so that the indicated horse-power of the "Iona" ought scarcely to be compared he thought with that of the "Ville de Douvres," as had been done by Mr. Head, when the engines of the "Iona" were not working at their full capacity.

The loss of steam pressure between the boiler and the valve-chest in the "Iona" was seen from page 61 to be but small, amounting to only 5 lbs., thereby proving that the supply pipes to that valve-chest were of pretty good size, although perhaps they might be still further enlarged with advantage. He enquired whether the valve-chest pressure had been taken with an indicator, as well as with a pressure gauge; and if so, whether the indicator diagram so produced was a straight line, or a fluctuating diagram such as was often obtained from valve-chests to which the supply pipes were too small. From an examination of the indicator diagrams taken from the cylinders of the "Iona" it would be seen that the capacities of ports and pipes and passages generally all through were well designed, because the loss of pressure at both ends was so small: at one end between the boiler and the high-pressure valve-chest, and at the other end between

(Mr. Alfred Saxon.)
the low-pressure cylinder and the condenser. In the "Tartar" there was about 11 lbs. loss of pressure between the boiler and the valve-chest, Plate 7, and again about the same between the latter and the high-pressure cylinder; and it appeared to him that in this steamer the engines were crippled all through in regard to size of pipes, valves, and port openings. Where the pipes and ports were not quite large enough, the point of cut-off was not so easy to determine in an indicator diagram; and this consideration seemed to him to confirm Professor Beare's explanation (pages 73–4) in regard to the "Tartar" engines. In the "Colchester," where there was a considerable loss of pressure between the boiler and the high-pressure cylinder, the steam-chest pressure was not given; but from the indicator diagrams he thought it would be found that the cut-off in the high-pressure cylinder was not arranged at the best point for utilizing as much of the boiler pressure as possible. In his own experience at any rate he had found that, where slide-valves or piston-valves did not give an effective cut-off, the cylinder pressure did not approximate so closely to the boiler pressure as it did if the cut-off were effective. The conclusion the author arrived at on this point he believed was correct (page 61), namely that there was little use in carrying high boiler-pressures where such a great deal of loss, as much as nearly 13 per cent. in one instance, occurred between the boiler and the high-pressure cylinder.

Reverting once more to the comparison he had already made of the "Ville de Douvres" with the "Meteor," a two-cylinder compound engine with a triple-expansion—although it was hardly fair to compare them unless they had been working at the same boiler pressure—it would be seen that considerably more power could be developed from the triple-expansion engine than from the other, because the two engines were here practically doing the same effective work, as measured by the mean effective pressure in their low-pressure cylinders (Table 26), but with a smaller consumption of feed-water in the "Meteor" per indicated horse-power per hour (Table 29). This was one great advantage resulting from the use of the higher steam-pressure and of triple expansion, which together allowed of the development of the power with greater economy.

Mr. Charles Cochrane, Past-President, referring to the loss of steam pressure in the "Iona" between the boiler and the high-pressure cylinder, considered that with the boiler pressure of 179·58 lbs. per square inch the loss of 5 lbs. between the boiler and the high-pressure steam-chest (page 61) clearly arose from the pipe being too small which conveyed the steam from the boiler to the steam-chest. Then there was a further loss of 17½ lbs. between the pressure in the valve-chest and the initial pressure in the cylinder, which must arise from the ports being too small or else from some movements of the valve-gear that were not perfectly correct. When it was suggested (page 61) that a boiler should not be constructed for such a high pressure as 180 lbs. if nearly 13 per cent. of this was to be lost between the boiler and the first cylinder, he would urge that, in view of the defects in steam pipes and ports and valve gear, it was absolutely necessary and most important to construct the boiler for 180 lbs. pressure, in order to get in the cylinder the initial pressure of 157 lbs. which was needed for developing the power required.

In regard to the relation of condensing water to condensed, the observations in page 69 of the paper appeared to him to contain much material for the future development of the whole subject, seeing that attention had also most properly been called in page 55 to the difficulty of measuring the large quantity of condensing water so as to compare it with that condensed. The best means he believed of ascertaining the quantity at the present time, where no direct measurement was as yet possible with a tank or meter, was to note the heating effect produced upon the condensing water, and to compare this with the measured temperature of the condensed water which was carefully weighed. By this means a pretty close approximation to the actual weight of condensing water employed would be arrived at. The only error he could see in such a calculation was that due to radiation from the condensing vessel. In the "Iona" and the "Ville de Douvres," which had been so ably compared by Mr. Head, there were certain points in connection with the relation of the condensing water to the condensed, which he thought ought to attract closer attention. In the "Iona" the vacuum obtained in the condenser was no less than 13·88 lbs. per square

(Mr. Charles Cochrane.)

inch (Table 26), whereas in the "Ville de Douvres" it was only 10·12 lbs. Why was this? The "Iona" had 9·47 square feet of condensing surface (page 69), over which passed 52·5 lbs. of condensing water per pound of steam condensed; whereas the "Ville de Douvres" had a diminished condensing surface of only 5·93 square feet, over which passed only 43·1 lbs. of condensing water per pound of steam. What then could be expected to be obtained in the latter case but such a low vacuum as 10·12 lbs.? The explanation given at the time of the trial he understood had been that everything was sacrificed to speed in the "Ville de Douvres"; but without presuming to criticise the design of her engines, he could not help thinking that the same speed might have been obtained with some greater economy by a modification in the arrangements of the condenser. With this view he was the more impressed on contrasting the temperatures of the circulating water in the two steamers, as measured at the inlet and outlet (page 69). From these it was seen that the "Ville de Douvres" had the further disadvantage of starting with the inlet water at 61·7°, while in the "Iona" it was only 55·8°, or something like 6° cooler. Moreover the rise of temperature in the "Iona," from 55·8° at the inlet, was only to 75·5° at the outlet; while in the "Ville de Douvres," commencing at the higher temperature of 61·7°, the water passed out at 85°, which was naturally a serious disadvantage to the economy of fuel.

In reference to the paper, he could not refrain from remarking what great praise was due to the author for the able way in which he had criticised the trials of these six vessels. Only a few years ago all that was depended upon in ocean traffic was the amount of coal consumption in any voyage; and there was no attempt to separate the duty of the boiler from that of the engine. This Institution had the credit for having originated and carried out the series of trials so ably superintended by their President, Professor Kennedy, which had led to the adoption of accurate methods for determining the duty both of engines and of boilers, in place of the rough and ready and inaccurate methods formerly followed.

Mr. DRUITT HALPIN was glad allusion had been made in the concluding paragraph of the paper to the simple and easy mode of measuring the feed-water in the "Ville de Douvres" by means of a meter. In the discussion upon some of the earlier trials (1889 page 296, and 1891 page 247), he had himself called attention to this mode of measurement, because he thought the substitution of a meter in place of cumbersome measuring tanks would help to popularise these trials amongst shipowners, seeing that trials could thereby be carried out with so little trouble. The late Mr. Sennett, a short time before he left the Admiralty in 1889, had put a meter to measure the feed in one of the large rams or cruisers, for enabling him to separate the duty of the boilers from that of the engines. Whether any experiments had been made with it he did not know; but as Mr. White appeared to think so highly of the present trials in regard to what the merchant navy had done, he hoped that perhaps the Royal Navy might now be looked to for some similar results. In a paper contributed to this Institution seven years ago from another branch of the public service, it had been shown that as much as from 34 to 39 lbs. of water per indicated horse-power per hour had passed through a stationary steam-engine experimented upon at Woolwich, when condensing, and from 40 to 51 lbs. when non-condensing (Proceedings 1887, page 494). Though he did not suppose anything of this kind was going on in the Navy, it would be interesting to know what really was the consumption of feed-water, now that it was shown it could be so readily measured by a meter.

The loss of steam pressure between the boiler and the first cylinder (Table 26), which had been already commented upon in the discussion as well as in the paper (page 61), was in his opinion a most serious matter, and he considered that not under any circumstances ought a boiler to be constructed to carry so high a pressure as 180 lbs., in order to get only 157 lbs. initial pressure in the cylinder. Some time ago in a compound engine working with a boiler pressure of somewhere about 160 lbs. this point had been accurately tested by stopping the engine on the dead centre, and then turning on the steam to enter through the lead of the valve and

(Mr. Druitt Halpin.)
fill the cylinder. The pressure in the cylinder was then marked by the indicator, and agreed correctly with that shown by the gauge on the boiler, which kept dead steady. There was therefore no question of the steam pipes in that particular instance; evidently they were amply large enough. But as soon as ever the engine was started, the result was that, although the boiler pressure remained steady at the same amount as before, there was at once a drop of 14 lbs. in the initial pressure in the cylinder. This was cured in a simple way and in a short time. The engine had an expansion-slide with variable stroke on the back of the main slide-valve; and the ports in the expansion-slide were of the ordinary form, that is, parallel through the whole thickness of the plate. The only alteration made consisted in cutting away the back edges of these ports with a chisel, so as to widen the ports out towards the back of the expansion-slide, roughly in the form of a "vena contracta," thereby facilitating the entrance of the steam through them. This had the immediate result of bringing up the initial pressure in the cylinder to the extent of some 11 lbs., that is, to within about 3 lbs. of the boiler pressure.

In Table 24, showing the heat lost by radiation from the boiler surfaces, the author had been good enough to give, in addition to the percentage lost, the rate of transmission also of the escaping heat in thermal units per square foot of surface per hour; and as in another column the difference of temperature between the steam and the air was given, all the required data were here furnished for comparing the rates of radiation, and the results were certainly most extraordinary. In the "Meteor" the thermal units escaping per square foot of heating surface per hour and per degree of difference in temperature were 10·1; in the "Colchester" 9·2; in the "Fusi Yama" 5·8; in the "Iona" 4·6; and in the "Ville de Douvres" 5·7. All of these, even the lowest, seemed extremely high results, because it might be taken generally that the transmission of heat either from steam-heated or from water-heated pipes into air was not more than about 2 thermal units per square foot per hour per degree of difference in temperature; and in some of the published experiments made by the President with his usual care it would be

found that, taking 75 per cent. as the efficiency of the stationary boilers experimented upon, the radiation amounted to only about 75 thermal units, instead of the large losses given in Table 24, ranging from 1,430 up to as much as 3,120 thermal units. The small loss he had mentioned of only 2 thermal units per degree pertained of course to ordinary cases where there was no strong draught; but by the production of a strong draught either artificially or accidentally the radiation might be increased up to five or six times as much. Although in the stoke-holds of marine boilers there was usually a great draught, he did not see how there could possibly be any draught strong enough to account for such an abnormal radiation. Presuming that the figures given were correct, he could not understand how such large losses by radiation were brought about, even including all the uncovered surfaces of the smoke-boxes, funnels, and all other parts.

In referring to the condensing water, it had been remarked by Mr. Cochrane that from the known weight of the relatively small quantity of steam going through the engine, and from the measured temperature of the condensed water and the rise in temperature of the condensing water, the quantity of the condensing water could be calculated, the only loss to be allowed for being that from radiation (page 101). If this were all, then in the same way, taking 15,000 thermal units in one lb. of coal, it might be practicable at once to calculate the evaporation in a boiler; but he did not see how the evaporation could be obtained from this one factor alone, because it would vary with different kinds of boilers and under different circumstances of combustion, and could be arrived at only by direct experiment in each particular case. By a rough and ready rule, from 25 to 30 times the weight of water was required for condensing the steam passing through the engine; but if the rise of temperature in the condensing water and the heat given off by the condensed steam were the only factors that were reckoned, it would be found that much less condensing water was wanted. The fact was that in condensing with jet condensers there was not steam alone to be dealt with, but also large and unknown quantities of air; and with surface condensers, instead of only

(Mr. Druitt Halpin.)
radiation from the condenser there were also large losses in transmission to be dealt with, causing the whole apparatus to be less efficient. [See also page 138.]

Mr. Josiah McGregor said no one could appreciate the trials dealt with in the paper more highly than he did, having himself been connected with the design, construction, and working of marine engines for a lengthened period, during which there had been a great number of changes in the methods of procedure, due as much he believed to trial and error as to a better understanding of the principles involved. There were few engineers who had had anything to do with the subject who had not been brought frequently in contact with questions upon which the present paper shed a flood of light. Sometimes they had made experiments on their own account; but usually such experiments had been conducted under circumstances which prevented reliable data from being obtained.

In the trials here dealt with there were indeed some peculiar and interesting results in regard to the boilers. Gauging the performance of a boiler by the pounds of feed-water per square foot of heating surface per hour, he noticed in Table 18 (page 39) a variation from 9·02 lbs. in the "Ville de Douvres" to 2·73 lbs. in the "Iona." The significance of this variation was perhaps more apparent on considering that, if the boilers of the "Iona" had been worked as those of the "Ville de Douvres" were, then fewer boilers in the ratio of one for every three would have been sufficient: which was certainly curious. This great extravagance of boiler power in the "Iona" was accompanied by no corresponding advantage in the performance; for he noticed that the efficiency of the boilers in these two steamers, as represented by the percentage of heat taken up by the feed-water, varied only from 69·2 per cent. in the "Iona" to 66·1 per cent. in the "Ville de Douvres." These trials showed that the percentage of heat taken up by the feed-water varied from 62·0 to 69·2 per cent. And the transmission of heat by the boilers varied nearly as the heat supplied; this he had himself found to be the case in a number of trials he had made in the Bay of Bengal with the steamer "Satara" belonging to the British India Steam Navigation Co., at a rate of heat supply intermediate between that

in the "Meteor" or "Colchester" and that in the "Iona," which were the two widest apart in the present series.

From the particulars given of these trials it was interesting to estimate the temperatures of the fires. He had thus found that the temperature in the "Meteor" was the highest, namely about 3,855° Fahr.; in the "Ville de Douvres" it was 3,241°; while in the "Iona" it was 2,465°. If the same method of estimating temperature was applied to the gases in the chimney, the results varied considerably from the temperatures actually found: which seemed to show that a considerable error existed somewhere. The air supply he suspected was chiefly accountable for the discrepancy. From Table 22 he inferred that the air was estimated from the chemical analysis of the gases in the chimney: he supposed from the quantity of oxygen found in the chimney. If all the oxygen found in the chimney was procured from the air, and it all went to oxidise the carbon and hydrogen, then of course the result would be correct; but he noticed that none of the hydrogen in the analysis of the fuel itself (Table 19) was accounted for in the chimney. That there must be some uncertainty about the air supplied was evident from the difference obtained with two precisely similar boilers in the same steamer: in the "Colchester" (page 50) the after funnel had 37 per cent. more air than the forward, with 10 per cent. less draught, the effect of which was only $1\frac{1}{4}$ per cent. greater consumption of fuel. Hence it was clear that considerable latitude must be given to the results recorded.

From Table 29 it was seen that the engines of the "Iona" consumed 13·35 lbs. of steam per indicated horse-power per hour, while those of the "Ville de Douvres" took as much as 20·77 lbs. of steam. A convenient way of estimating the size of an engine in relation to its power was to take the cylinder capacity per indicated horse-power per minute; and when this calculation was made from the figures given in the paper, it was found that the "Iona's" performance was obtained with a size of engine equal to 16·25 cubic feet of cylinder capacity per indicated horse-power per minute, while the "Ville de Douvres" had only 9·61 cubic feet: so that proportionately the engines of the "Iona" were nearly double the size of those of the "Ville de Douvres."

(Mr. Josiah McGregor.)

The defective vacuum in the "Ville de Douvres" he thought was to be accounted for most probably by some undetected leak; for the condenser appeared to have been supplied with a full quantity of water, and it extracted its full quantity of heat. From the data previously given (Proceedings 1892, page 163, line 80) he calculated that as much as 4·29 lbs. of circulating water was supplied per hundred thermal units, and in the "Iona" 5·07 lbs.; so that the difference was not so considerable as to account for the difference in vacuum. One cause which might account for a part, but only a part, of the deficient vacuum in the "Ville de Douvres" was the small air-pump capacity, amounting to only 0·80 cubic foot per pound of feed-water, whereas the "Iona" had 1·45 cubic foot. The great deficiency in vacuum in the "Ville de Douvres" must therefore be accounted for by some other cause than had hitherto been assigned for it.

Mr. BRYAN DONKIN believed that meters were now used in the French and German navies for measuring the feed-water.

It might be interesting to draw attention to the maximum and minimum results of the six trials reported, three of two-cylinder compound engines and three of triple-expansion. The pressures of steam varied from 70 to 180 lbs. absolute per square inch (Table 18). The boiler efficiencies varied but little, only from 62 to 69 per cent. The feed-water evaporated from and at 212° Fahr. varied per lb. of coal from $8\frac{1}{4}$ up to as high as $10\frac{5}{8}$ lbs.; and per square foot of heating surface from $3\frac{1}{4}$ to nearly 10 lbs. per hour (Table 21). The consumption of coal per square foot of grate per hour varied $2\frac{1}{2}$ times, namely from 12 to 31 lbs. The engine efficiency (Table 29) varied from only 11 per cent. up to 17 per cent.; the revolutions (Table 25) from 37 to 87 per minute; and the indicated horse-power (Table 27) from 370 to 3,000. The feed-water per indicated horse-power per hour, of course with different pressures of steam, varied as much as $1\frac{1}{2}$ times, namely from $21\frac{3}{4}$ lbs. in the "Colchester" to $13\frac{1}{3}$ lbs. in the "Iona." From the "Iona" trial, which seemed to have been the best of all, the following were some of the principal results. The consumption of coal per square

foot of grate per hour was about $22\frac{1}{2}$ lbs., and per indicated horse-power per hour $1\frac{1}{2}$ lb. The feed-water evaporated from and at 212° Fahr. per square foot of heating surface per hour was $3\frac{1}{5}$ lbs., and per lb. of coal $10\frac{5}{8}$ lbs.; and the boiler efficiency 69 per cent. The funnel temperature was the lowest of any, namely 452°. The velocity of the gases through the tubes (Table 23) was also the lowest, namely 500 feet per minute. The revolutions were 61 per minute. The boiler pressure was the highest of any, being 180 lbs. absolute per square inch; and at the same time the condenser vacuum was the best, being only $\frac{3}{4}$ lb. absolute, or $13\frac{7}{8}$ lbs. below the atmosphere. The indicated horse-power was one of the lowest, 645; and the feed-water per indicated horse-power per hour was the lowest, $13\frac{1}{3}$ lbs. The engine efficiency was the highest, namely 17 per cent. These results seemed to be due to the great expansion used, namely 19 times (page 68), notwithstanding that the high-pressure cylinder alone was jacketed. An interesting addition to the paper would be the proportion of total jacketed surface to the total internal surface touched by the steam. If possible in any future trial of a good marine engine, it would be desirable to try the engines with all the jackets in use, and with none. Such an engine ought to have a jacket surface of at least from 60 to 70 per cent. of its total surface exposed to the steam; whereas engines were often called jacketed when they had no more than only 30 or 40 per cent. of their surfaces jacketed. The conclusion to be drawn from the whole of these careful and accurate trials seemed to him to be that, in order to obtain the best economy, there should be larger heating surface in the boilers, greater expansion, higher pressures of steam, and hotter cylinder walls or thoroughly jacketed cylinders, especially the cylinder covers.

Mr. CHARLES E. COWPER suggested that Capt. Sankey should be asked to give some explanation* of the method by which the ordinary indicator diagrams were transferred to the theta-phi chart so as to produce the theta-phi diagrams. The literature on this

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* See footnote on page 83.

(Mr. Charles E. Cowper.)

subject he believed was at present limited to three papers:—the original paper read by Mr. Macfarlane Gray at the Paris Meeting of this Institution (Proceedings 1889, page 411), which treated the matter entirely from a theoretical point of view; a paper read by Mr. Willans to the Institution of Civil Engineers in 1888 (Proceedings vol. xciii page 133, and vol. xcvi page 240), in which he introduced the chart; and his further posthumous paper in last year (vol. cxiv page 8). The late Mr. Willans was a practical engineer and maker of steam engines, and believed thoroughly in the θ ϕ chart; and their present President had at the Paris Meeting expressed his admiration of it (Proceedings 1889, page 458). On the occasion of the discussion last year at the Institution of Civil Engineers (vol. cxiv page 87) he had himself worked out a numerical example from the usual test-book formula for work due in heat units, and had shown the agreement between the result so obtained and the area representing the same in the θ ϕ chart. Capt. Sankey had now made a great step in advance by adding the constant-volume curves to the original θ ϕ chart; and, with the assistance of these curves, drawing on the chart θ ϕ diagrams representing actual indicator diagrams. In the early days of the steam engine, indicator diagrams had no doubt looked to the majority of engineers almost as unintelligible as the new θ ϕ diagrams seemed at present; but every mechanical engineer conversant with steam engines now knew the meaning of every part of an indicator diagram, and appreciated the information which it afforded. Who could tell therefore what might not be done in the future with the θ ϕ chart and diagram?

The PRESIDENT was sure that the Members must all be as desirous as himself to hear something from Mr. Macfarlane Gray on the subject of his theta-phi diagram, of which the high practical value was now rendered so clearly apparent from the illustrations furnished by Capt. Sankey.

Mr. J. MACFARLANE GRAY regretted that he was not able to offer any remarks on this subject, steam-engine performance being one of the subjects about which the Board of Trade had made a rule that

the individual opinion of any of their engineer officers must not be made public. His application that an exception might be made in this instance had today been refused.

Mr. John Phillips remembered that on the occasion of the first report of the Committee upon these Marine-Engine Trials it had been pointed out by the President (Proceedings 1889, page 253) that the object of the trials was not to form a basis on which to criticize the design or construction of the machinery, but to ascertain the results obtained from its working. The fact that these results were now grouped together in the present paper he therefore thought did not afford ground for any comparison between the different kinds of machinery, except in regard to what each had done. A comparison had been drawn (page 100) between the "Tartar" and the "Iona," and it had been stated that in the former the engines were crippled by the steam-pipes, ports, and valve-gear; and attention had been called to the fall of pressure between the boiler and the high-pressure slide-valve casing as being so much more than in the "Iona." This did not appear to him to be a correct inference to draw from Table 26; for if the boiler pressure and the initial pressure in the high-pressure cylinder were compared, it would be found that the fall in pressure in the "Tartar" was 22·20 lbs. and in the "Iona" 22·50 lbs., or practically the same in both. This difference of pressure however really showed in his opinion no defect of construction in either engine. In the "Iona" the true explanation he considered was that the engine was throttled and linked up to such an extent as was found best for the speed at which it was intended to run, and thereby the initial pressure was correspondingly reduced in the high-pressure cylinder. Referring to the question raised in the paper (page 61) as to the use of a boiler pressure so high as 180 lbs. absolute when the initial pressure in the high-pressure cylinder was not more than 157 lbs., it had been stated by Mr. Mudd on a former occasion (Proceedings 1891 page 278) that there was economy in this plan of working the steam; and in this view he coincided. Neither in the "Tartar" nor in the "Iona" were the engines working at full power; and therefore no proper

(Mr. John Phillips.)

comparison could be made between these vessels and the "Colchester," the "Ville de Douvres," and the "Meteor," because the weight of the machinery per indicated horse-power, as seen in Table 34, must necessarily be greater when an engine was working below its intended power than when the same engine was working up to its full power.

By way of attempting to diminish the difficulty of arriving at a conclusion as to the supposed priming in the "Tartar," he enquired whether the chimney of that steamer had a damper, and whether the temperatures of the funnel gases were taken on deck at about the same level as in the "Iona."

Mr. FREDERICK EDWARDS replied that there was a damper in the chimney of the "Tartar;" and the point at which the temperature of the gases was taken was above the damper, about at the level of the deck he believed, but he was not certain.

The PRESIDENT explained that the temperature of the gases was taken lower down in the "Tartar" than in the "Iona." For some practical reasons which he did not remember, it was necessary in the "Iona" to go higher up the funnel for measuring the temperature of the gases.

Mr. PHILLIPS doubted whether the heat supposed to be carried away in the funnel gases could be rightly regarded as the reason why so much of the heat was not utilized in evaporating the water. In his own experience as a sea-going engineer, he had never found smoke-box doors in a marine boiler which did not let more or less air leak in all round them; and of course the larger the door, the greater was the length of joint and attendant leakage. There were also other places in which air leakage could occur. If therefore the samples of the funnel gases were taken at any height above the tubes, where the entering air from all these leakages had had an opportunity of mixing with the gases escaping from the tubes, it seemed to him that no conclusion drawn from an analysis of the gases could correctly represent what had actually taken place in the

combustion of the fuel. It was with great diffidence that he mentioned this point, implying as it did a possible error in regard to some of the conclusions in the Committee's report of one of the trials.

A suggestion was made in page 47 of the paper that the rolling of the "Tartar" during the trial had caused priming. Having however been at sea both in bad weather and in good weather, he had never found a boiler prime because the ship was rolling. Moreover the water in the boiler, especially with engines having surface condensers, contained comparatively but little air; and as far as he was aware water agitated without air in it did not foam in the same way it was supposed to do when it contained its normal quantity of air. This he thought was another reason why priming had not actually taken place. In the report of the "Tartar" trial (Proceedings 1890, page 232) it was stated that the steam-jacket of the high-pressure cylinder could not be used; but no satisfactory reason was given for this. This led him to think, from what had happened to himself and others in the use of steam-jacketed cylinders, that without any disparagement whatever of these engines there might have been a leak in the joint of the cylinder liner, and water or steam could consequently have leaked into or out of the cylinder and the jacket, the pressure in the jacket ranging from nothing up to 50 lbs. above the atmosphere; there must have been a loss of heat in some way, for when the jacket was not heating the cylinder steam it was cooling it. These various points required careful consideration before coming to the conclusion that priming had occurred. Any condensation that might take place between the boilers and the high-pressure slide-valve casing would appear as water in the cylinder, but it would not of necessity be priming water.

Mr. E. C. DE SEGUNDO, referring to the anomaly in the water consumption during the trial on board the "Tartar," was personally conscious of the fact that there was water in the intermediate cylinder, for he happened to be one of the members of the observing staff and was scalded several times. But he was hardly able to accept as satisfactory the explanation offered by Mr. Phillips, inasmuch as the conclusion could not be avoided that, if all the

(Mr. E. C. de Segundo.)

feed-water had been evaporated by the boiler, it would have meant an extraordinary evaporative power in the boiler per pound of fuel. The larger water consumption in the "Tartar" might be due to leakage of steam past the valve; and from the figures given by Professor Beare there was no doubt in his own mind that there had been such a leakage, and this might have been sufficient in amount to account for the higher consumption of water. The difficulty yet remained that in spite of this the coal consumption was so small. The latter might be explained in two ways: one was that the whole of the water passing through the measuring tanks might not have reached the boilers; the other was that, owing to the pitching and rolling of the steamer, some error might have occurred in reading the indications of the spring balance with which the coal was weighed; or possibly the Lascar firemen might occasionally have shovelled coal direct from the bunkers without its having been weighed. A comparison of the results of the "Meteor" and "Tartar" trials showed that, while the engines were similar in size and the boiler pressure about the same, the "Tartar" was working under load conditions extremely unfavourable to economy. The coal consumption per square foot of grate per hour was 11·93 lbs. in the "Tartar" as against 19·25 lbs. in the "Meteor" (Table 18). But in spite of this the coal burnt per indicated horse-power per hour was 1·77 lb. in the "Tartar" as compared with 2·01 lbs. in the "Meteor," while the apparent water consumption per indicated horse-power per hour (Table 29) was about 25 per cent. higher in the "Tartar" than in the "Meteor."

Mr. FREDERICK EDWARDS wished to thank the author for the great trouble he had taken, and the great amount of work he had done in preparing the present paper; and also to point out the great importance of the work that had been done by the Committee. If engineers would take these results to heart, and do their best to improve their engines, thousands of tons of coal would be saved.

With regard to the "Fusi Yama" trial, as he had mentioned once before (Proceedings 1890, page 257), the run during which it took place (page 35) was not an ordinary voyage, but was her

first voyage under his supervision, and just after she had been overhauled. The pistons had been fitted with new spring rings, but the cylinders had not been newly bored out; the consequence was there was considerable leakage past the pistons. In this connection it might be of interest to mention how he tested the steam-tightness of the pistons in steamers under his charge. As soon as the steamer came in, the top covers of the cylinders were lifted, and the tops of the cylinders were filled with hot water; the bottom cover of the large cylinder was also removed, and the pistons being then moved slowly up and down in the cylinders, any leakage past them was seen running out below. This was collected and measured, and a record was thus obtained of how much the piston leaked in a given time. The plan was found to save a good deal of trouble, and had often proved that a piston leaked badly in particular positions, although its appearance and general condition gave the impression that it was in good order and steam-tight. The indicator diagrams did not afford the means of discriminating accurately between leakage at the valves and leakage at the pistons; and the best way of ascertaining the latter he considered was by means of water, according to the method just described.

With regard to the supposed priming in the "Tartar," he could not think that the boilers were priming as mentioned in the report. As he had said before (1890, page 259), these boilers had more steam space in proportion than any of the other boilers under his care. As a rule they were always worked with the main feed-pumps, with which, except during the trial, there had never been any trouble; and the trial had been started with the main feed-pumps pumping water into the boilers. When it was found however that the feed-pumps were not feeding as regularly as could be wished, recourse was had to the donkey, which was used as a stand-by for pumping water into the boilers. He had since asked the chief engineer whether it was possible for any of the water to have been going overboard; and he had understood from him that there might have been a slight leak in some of the donkey connections, and that possibly some of the water might have been going in the wrong direction.

(Mr. Frederick Edwards.)

As to the consumption of coal in the "Tartar" (page 114), the firemen he thought would not have had any inclination at all to use unweighed coal out of the bunkers. As he believed the author had gone through the log sheets carefully, he would doubtless be able to state whether he had found any variation between the two stoke-holds in regard to rate of coal consumption, on comparing one stoke-hold with the other at the opposite end of the boilers: because of course the log sheets would not be likely to show the same rate of consumption in both equally, if unmeasured coal had been used in either or in both.

Professor BEARE said as far as he could make out from the log sheets and from plotting the consumption of coal there had not been much variation between the two stoke-holds. In the latter part of the trial there had been rather more coal burnt in the after stoke-hold; but it had been a gradual and uniform increase, and did not in the least suggest possible errors of measurement. The rates of coal consumption appeared to have been fairly uniform in all the boilers.

Mr. EDWARDS felt satisfied that the records of the coal consumption were correct.

As some of the faults brought to light by the aid of the theta-phi diagram had been pointed out by Capt. Sankey (page 89), it would be highly interesting if he would kindly show further how the engines were to be put right in those particulars.

The temperatures of the circulating water at the inlet and the outlet, which were mentioned in page 69 as having been taken only in the "Iona" and the "Ville de Douvres," were measured also in the "Tartar." They were 55° at the inlet and 89° at the outlet, showing a rise of 34°.

With regard to the back-pressure in the low-pressure cylinder, he had taken a great deal of trouble to get it lower in his steamers than even in the "Iona," and he was glad to say his endeavours had now been rewarded. Some engineers with whom he had discussed the question of back-pressure seemed not to appreciate the importance of a good vacuum, but rather to think it was better to work with a

little less vacuum and have the feed-water hotter. Having gone carefully into this matter he had found that, taking a triple-expansion engine with 74-inch low-pressure piston and 54 inches stroke, and supposing the engine to be working at 55 revolutions per minute with about 3 inches of mercury or about $1\frac{1}{2}$ lb. per square inch more back-pressure than was necessary, this would be equivalent to a loss of about 96 horse-power. The practical question therefore was, what did it cost to save this 96 horse-power. The steam consumption was 14 lbs. per I.H.P. per hour, and each pound weight of steam took up 1,122 thermal units. Allowing 35° for the loss in temperature of the feed-water, the thermal units required per I.H.P. per hour for the 96 horse-power would be about 8,166 : whereas the bulk of the power, or say 1,600 horse-power, cost 15,708 thermal units per I.H.P. per hour. In other words the extra power obtained by working with a 3-inch better vacuum in the condenser cost a little more than half what the original power cost per I.H.P. If however the difference between the back-pressure in the cylinder and the absolute pressure in the condenser were reduced to the same extent, it cost practically nothing to save the same amount of power, because the temperature of the feed-water was not reduced This difference he had frequently found to amount to 2 or 3 lbs. per square inch, apart from the absolute pressure in the condenser. In some cases indicator diagrams had been sent him showing as much as 7 lbs. back-pressure in the low-pressure cylinder, owing to the importance of reducing it not having been understood. According to his own experience the vacuum gauges in ordinary use were untrustworthy for accurate work; and he had found it necessary to put indicators upon the condensers in order to check the gauges. Nine months ago he had sent a ship away which had now just come back. She had been furnished with two vacuum gauges of the ordinary kind, the best he could get, which he had had specially tested beforehand ; but during the whole of the voyage the chief engineer reported that they had differed by about one inch of mercury or $\frac{1}{2}$ lb. per square inch. It was of course highly important to be able to know what the vacuum really was, otherwise it could not be ascertained whether the back-pressure arose between

(Mr. Frederick Edwards.)

the cylinder and the condenser, or whether it was absolute pressure in the condenser; and he was now fitting mercurial gauges on the condensers, so as to find out the absolute back-pressure that there was in them.

Professor DAVID S. CAPPER, referring to the suggestion just made by Mr. Edwards that some of the difference between the back-pressure in the low-pressure cylinder and the pressure in the condenser might be due to errors in the vacuum gauges, had no doubt this was the case, though an equally possible source of error might be incorrect indicator-readings. Having tested many indicators he had almost invariably found backlash present in the pencil levers. Errors due to this cause seemed to be more marked at high than at low pressures; but he had frequently found backlash sufficient to account for variations of at least one pound per square inch at atmospheric pressure. These indicators were tested under steam upon a mercury column specially designed for the purpose in the engineering laboratory at King's College. It was worthy of remark that the kind of indicator which he had hitherto found as free from this defect as any that he had tested was that used in the "Meteor" trial, where the variation between low-pressure cylinder and condenser was least.

One other point, to which attention had not been specially drawn, was shown with remarkable clearness by these trials: namely the influence of jacketing upon the dryness of steam, especially with reference to slow piston-speeds and high ratios of expansion. Of the three sets of triple-expansion engines mentioned in the paper, two had the intermediate and low-pressure cylinders jacketed, and one, the "Iona's," had neither jacketed. In the former the dryness fraction remained fairly constant, in the "Meteor" slightly dropping between the intermediate and low-pressure cylinders, and in the "Tartar" somewhat increasing in value. But in the "Iona" there was a marked drop in the percentage of steam present, namely from 75 per cent. before release in the intermediate cylinder down to only 59 per cent. before release in the low-pressure cylinder (Table 32). Comparing this result with the three two-

cylinder compounds, all non-jacketed, there was the same large condensation shown in the low-pressure cylinder in two out of the three. In the third, namely the "Ville de Douvres," a marked difference was noticeable, for the drop between the end of the high-pressure stroke and the end of the low-pressure stroke was only from $79\frac{1}{2}$ down to $72\frac{1}{2}$ per cent. of steam present. The explanation of this variation would appear if comparison were made between the several piston-speeds (Table 25), areas of cooling surface per pound of entering steam per stroke (Table 33), and ratios of expansion (page 68). In the "Iona," with a piston speed of 397 feet per minute and a large area of cooling surface per pound of entering steam per stroke, namely 24·32 square feet up to cut-off in the high-pressure cylinder, there was a ratio of expansion of 19 times with steam pressure of 180 lbs. absolute. Whereas in the "Ville de Douvres" the higher piston-speed of 442 feet per minute was united with the lower cooling area of 9·42 square feet per pound of entering steam up to cut-off in the high-pressure cylinder, and the much lower expansion of only 5·7 times with 120 lbs. steam pressure. These trials therefore again emphasized the fact that the most important cylinder to jacket was the low-pressure cylinder, especially in triple compound engines with high ratios of expansion and slow piston-speeds. As would of course be expected, jackets were of less importance with high speeds and low ratios of expansion.

Mr. William Schönheyder, having had some experience both in the manufacture and in the use of water meters, had found no difficulty in getting accurate results with them; a number of his own were now in use for feeding boilers and for other purposes, both with hot and with cold water. Through the late Mr. Sennett, as already mentioned (page 103), a meter had some years ago been placed by the Admiralty on board the "Medusa"; and since then, after careful and prolonged tests, the Admiralty had adopted several of his own meters both for cold water and for hot, and he believed they had been used on board ship with entire success. But as to measuring the circulating water from the surface condensers, he did not see any possibility of doing so by means of a water meter; the

(Mr. William Schönheyder.)
volume was of course far too big to be measured by an ordinary meter. But it might be measured he thought by a method similar to that adopted on land for measuring large volumes, namely by a weir: not an open weir, but a closed weir, that is, a hole in the side of a tank specially provided. The water from the circulating pump after passing through the condenser would be discharged into the tank, which should be closed at the top; and care should be taken that air was admitted into the upper part, while the lower part should have a hole in a gauge-plate in the side of the tank. The pressure might be taken by some kind of continuous indicator placed alongside the hole. In this way accurate results might be obtained, although he was not sure that any great gain would result from the measurement. Space on board ship was so cramped that in many cases it might be difficult to adopt such a plan; but in some instances it might be adopted if found desirable.

Mr. W. G. Walker thought it would be difficult to say which was the most efficient steamer in these six trials, because the total efficiency was made up of so many factors, all of which would have to be taken into consideration. There were the thermal efficiencies of the boilers and of the engines, the mechanical efficiency of the engines, and the efficiency of the screw propellers, besides many others. In thermal efficiency Table 29 certainly showed that the triple engines headed the list, the "Iona" having the high efficiency of 17·1 per cent.; but to take this one single efficiency or any other single factor as an indication of the ultimate efficiency of the vessel would be misleading. Another way was to compare the indicated horse-power per ton of machinery, as in Table 34, where it was seen that the "Iona" came out last with only 3·2 indicated horse-power per ton; this comparison was good so long as the piston speeds were equal, but when they varied it was useless. A better method he thought would be to compare the "indicated thrust" in lbs. per ton of machinery—using the term "indicated thrust," introduced by the late Mr. Froude (Institution of Naval Architects, 1876, vol. xvii, pages 168–9), to denote what would be the thrust of the propeller if the indicated horse-power were employed wholly in

creating thrust: so that indicated thrust = indicated horse-power × 33,000 ÷ (pitch of screw propeller × revolutions per minute). Having calculated the indicated thrust by this formula for each of the six steamers tried, he had found that the "Fusi Yama" stood first, with an indicated thrust of 135 lbs. per ton of machinery; next came the "Ville de Douvres" 127 lbs., the "Iona" 119 lbs., the "Meteor" 102 lbs., the "Tartar" 98 lbs., and the "Colchester" with 94 lbs. thrust per ton of machinery. It was of interest to notice that in this mode of measurement the indicated thrust per ton of machinery became reduced with an increase in the number of cylinders. Last summer he had carried out some experiments with an engine of rather large size, having a single cylinder 56 inches diameter with 72 inches stroke, in the "Ravenswood," a paddle-wheel passenger steamer used on the Bristol Channel service. She was 220 feet in length, with a displacement of about 420 tons, and was fitted with two haystack boilers working at 60 lbs. pressure. Her speed was 17 knots, with 1,600 indicated horse-power. The thrust he had calculated to be 158 lbs. per ton of machinery, which was higher than any of those he had just given. It certainly seemed to show that, if the number of cylinders or the number of expansions were increased, the performance fell off; and that in considering the number of expansions it was also necessary to bear in mind what was lost by increased weight of machinery. The effect of back-pressure had been strongly brought under his notice in the "Ravenswood," where he had found that there was a difference in back-pressure of $5\frac{1}{2}$ lbs. per square inch between the cylinder and the condenser. On tracing it by taking indicator diagrams at various points from the cylinder to the condenser, he had found that nearly the whole falling off occurred in the valves; the loss between the exhaust pipe and the condenser was very small compared with that between the cylinder and the exhaust pipe: there was a difference of about 4 lbs. between the back-pressure in the cylinder and the pressure in the exhaust pipe. In one or two other steamers with similar single-cylinder engines his experience had been the same, that the back-pressure always appeared to occur between the cylinder and the exhaust pipe. If the back-pressure was reduced, he agreed

(Mr. W. G. Walker.)

with Capt. Sankey (page 91) that it was not all gain, although on the whole there was a gain of power. From Table 28 and page 59 of the paper it looked as though a reduction of the back-pressure was regarded as all gain; but in the "Ravenswood" he had found clearly that it was not all gain, because the conditions in the cylinder were so completely altered. On reducing the back-pressure by $1\frac{1}{2}$ lb. per square inch, which he had done by increasing the ports, he had found that the steam pressure above the atmospheric line was slightly reduced, although there was a considerable gain in power: the horse-power was increased by about 150, with corresponding increase of speed.

Mr. Leslie S. Robinson wished the Committee could yet extend their labours by conducting a series of progressive trials in regard to power, like those conducted in the navy with regard to speed. The engines dealt with in some of the six trials had been working pretty nearly up to the full power they were designed to work at. The engines in the navy seldom did so, and under ordinary circumstances would be running perhaps at a fifth to a tenth of their full power. It would be a great help to those who had to do with designing marine engines for economical working if the Committee could with the aid of the Admiralty conduct a series of experiments progressing from a speed of say ten knots up to the maximum speed when the engines were working at their full power. Another point, which had not yet been alluded to beyond the mention made of it in page 36, was the difference between the closed ash-pits in the "Iona" and the closed stoke-holds in the "Ville de Douvres." These two plans of using forced draught produced somewhat different results, as seen from Tables 18 and 21; but the boilers differed so greatly that it was impossible for any practical conclusions to be drawn: although certainly as the figures stood they were in favour of the closed ash-pits adopted in the "Iona."

Mr. Mark Robinson observed that on board ship the indicated horse-power only could be ascertained; it would be of advantage to marine engineers if attention could be fixed also upon consumption

per effective horse-power, as it had to be in the trials of electric-light engines. While the "Iona," profiting by her 19 expansions (page 68), might fully deserve her high place, it was probable that the "Meteor," for instance, with her 10·6 expansions and her relatively small cylinder and piston-ring friction, would have held a better position if the steam used could have been measured per effective horse-power; and the remaining difference would be to some extent balanced by a fair allowance to the "Meteor" for her relatively lighter and cheaper engines. There were points to be borne in mind upon the other side, such as the lighter and cheaper boilers required, for an equal horse-power, to give steam to the more economical but heavier and costlier engines; and in seeking for a low consumption per indicated horse-power it might perhaps not be the case that any marine engineer had yet gone beyond the limit at which there was also a gain per effective horse-power. But in land engines he believed this had been done; and the subject was worthy of attention, for frictional loss in the engine was one of the factors that entered into the complex formula by which the marine-engine designer had to be guided, and unhappily too little was known about it. At the works of his firm at Thames Ditton they hoped soon to be able to test land engines upon the brake up to at least 700 horse-power. Might it be hoped that large marine engines of various types would some day be tested in the same way?

Professor BEARE desired to acknowledge the kind way in which Mr. White (page 75) had spoken about the paper; and to thank him for supporting the suggestion offered at the end of the paper that shipowners should have systematic tests made of the machinery in their steamers. He could not quite concur in the explanation given by Mr. Mudd (page 81) as to the large initial condensation in the high-pressure cylinder of the "Iona," which he had accounted for as probably due to the high-pressure valve-chest acting as a jacket to the intermediate receiver, whereby a good deal of steam was condensed in the valve-chest, producing some of the wetness observed in the cylinder. This explanation seemed to him not fully to cover the facts, because the steam-chest was drained, so that any steam

(Professor Beare.)

condensed in it from its jacket action would mostly have been drained off, and would probably not pass in any considerable amount into the cylinder. Moreover if the steam-chest had not had the receiver on the outside of it, it would have had the atmosphere, and the temperature of the atmosphere was lower than that of the receiver; therefore it would have radiated heat into the atmosphere just as it did into the receiver, with consequent condensation. External radiation of course took place from every valve-chest.

As to the overlapping of the indicator diagrams from the high-pressure and intermediate cylinders when plotted on a time base, Mr. Mudd's explanation (pages 79–80) seemed to apply only to the particular case of the "Iona," and not to be a general explanation. In regard to the boiler radiation (page 82), he would point out that, although perhaps some of the 13 per cent. loss put down as unaccounted for could have been accounted for by taking the temperature of the gases at a lower level, say at the smoke-box, yet it would still have remained a loss due to radiation, being then due to radiation from surfaces between the smoke-box and the higher level at which the temperature was actually measured.

In connection with the most interesting remarks made by Capt. Sankey, and the heat diagrams he had given for three of the steamers, he hoped, if it was not asking too much, that he would also kindly prepare similar diagrams for the other three steamers. [See page 130.] The results so brought out in regard to the trial of the "Tartar" seemed to him to confirm what he had himself arrived at in his later investigations, though Capt. Sankey's calculation (page 89) of from 18 to 25 per cent. as the amount of priming seemed to go even beyond the amount apparently to be accounted for. It would be a satisfaction therefore if this percentage could be re-calculated, in order to make sure that the figures were right in showing so great an amount of priming. It had been suggested by Capt. Sankey (page 89) that, if the oscillations of the water in the boiler synchronised with the rolling of the ship, a violent disturbance might have been produced at the surface of the water in the "Tartar" boilers; and therefore the explanation in page 47 that the priming was probably promoted by the rolling of the ship seemed to be not so much out of the way (page 113).

The saving of the back-pressure between the condenser and the low-pressure cylinder had also been referred to by Capt. Sankey (page 91) as not being wholly economical. Any reduction of back-pressure meant of course increased range of temperature in the cylinder, and therefore probably greater initial condensation, reducing the apparent saving shown in Table 28. Whether this difference of pressure between the cylinder and the condenser was always a real fact, or whether it was partly or wholly due to gauge or indicator errors, as suggested by Mr. Edwards (page 117) and Professor Capper (page 118), he was not certain. The calculations made by Mr. Edwards (page 117) were highly interesting, as showing the benefit of a good vacuum with cooler feed-water in comparison with a bad vacuum and hotter feed-water. How the latter could be the more economical he failed to see, notwithstanding that there was of course an advantage in the feed-water going hotter into the boiler, not merely for economy's sake, but also for the better working of the boiler.

In the heat balance-sheet given in Table 18, the balance unaccounted for was put down as mainly due to radiation (page 95). It was this which gave the appearance of such a large amount of radiation per square foot of cooling surface of the boiler, as seen in Table 24, which was referred to by Mr. Halpin (page 104). In this particular however he did not in the least pretend that Table 24 was absolutely accurate. As some sort of check, the figures in Table 24 had been calculated on the supposition that the area of radiating surface was just that of the shell of a plain cylindrical boiler with the addition of its two ends. There was however a large amount of additional radiating surface besides, inasmuch as in every trial the funnel temperatures were taken at some height above the boilers, and in one or two of the trials at a pretty considerable height above; and from all this additional surface, having on one side of it the highly heated gases from the furnaces, the loss by radiation would be much greater than from the boiler shell itself. The estimate in Table 24 therefore, including no more than the boiler shell, was intended only as an approximation; and his idea in framing it was that the figures should be taken

(Professor Beare.)
not as absolute but as comparative, as a test whether the heat balance-sheet in Table 18 might be regarded as fairly accurate in other respects, apart from the loss by radiation. In some experiments of his own on the radiation from the surface of a boiler well clothed with non-conducting composition, he had found the loss from the shell and ends only to be about 350 thermal units per square foot per hour; in the same boiler uncovered it was 750. These were losses in a closed boiler-room absolutely free from currents of air, with a steam pressure of about 100 lbs., and an air temperature of about 100° Fahr. in the case in which the boiler was uncovered, and 80° in the other.

The pressure in the valve-chest of the "Iona" he believed had not been taken with an indicator (page 99); it had been taken with gauges, and the gauges had been checked. No calculation had been made as to the velocity of the steam in the pipes in any of the trials. So long as it was certain that there would be a loss of steam pressure (page 101) between the boiler and the engine, as had been the case under the conditions of trial in the "Iona," a boiler carrying 180 lbs. absolute pressure was of course necessary, in order to obtain the required pressure in the engine. What he had meant to convey by the remark in page 61 of the paper was that it seemed to him feasible for engineers in some way or other to alter the design of their engines, either in the stop valves or in the steam pipes or in the valve-chests and cylinder ports, so that such a great loss of pressure might be saved. The same point had been referred to by Mr. Phillips in connection with the linking up of the engines when not working at their full power (page 111); but though he could not pretend to go behind what the maker of the engines found most suitable for their working, he failed to see how it could be economical to generate steam at a high pressure in the boiler, and then to use it in the cylinder at a considerably lower pressure. The only advantage he could concede was that mentioned in page 61: that the wire-drawing of the steam produced superheating, whereby initial condensation might to a certain extent be prevented. It was a point however which he thought deserved some consideration on the part of the designers of

mairne engines; and he was glad that his views had been supported by Mr. Cochrane (page 101) and Mr. Halpin (page 103).

Attention had been called by Mr. McGregor (page 106) to the remarkable disparity between the "Iona" and the "Ville de Douvres" in many of their conditions, and yet their closely similar boiler efficiency. It must be remembered that the "Iona" was designed for long voyages, and the "Ville de Douvres" for only short voyages of a few hours; and he thought it was questionable whether, if the boilers of a steamer such as the "Ville de Douvres" were to be driven for weeks together at the rate at which they were actually driven in one of her short voyages, their economy would be anything like what it was during her short passages across the channel. In judging the performance of each steamer it was always necessary to bear in mind the particular service for which she was designed.

In the analyses of the funnel gases, referred to by Mr. McGregor (page 107), no corrections were necessary to allow for the oxygen used in the combustion of the hydrogen in the fuel, because the analyses, as given in Table 22, were for the dry funnel gases. But the weight of dry air per pound of fuel, both theoretical and actual, was also stated; and in this the oxygen required to burn the hydrogen was included. The analyses given of the gases did not profess to be analyses of the whole contents of the funnels, but only of the dry gases which passed away through them; there was no practical way in which the steam produced by the combustion of the hydrogen in the fuel could be collected along with the dry gases. Its weight however was easily calculated, and therefore the amount of oxygen used in its production. As to the great difference in the air supply to the aft and forward boilers in the "Colchester" and also again to some extent in the "Ville de Douvres," he could not offer any explanation. The fact was there, and he had no reason to doubt that it was recorded correctly.

It was most important he thought to have proved, as pointed out by Mr. Head (page 97), that forced draught gave as perfect a combustion of the fuel as natural draught with the same weight of air per pound of fuel.

(Professor Beare.)

The proportion of jacketed surface to the total surface touched by the steam up to the point of cut-off (page 109) in the jacketed cylinders of the "Meteor" and the "Iona" had been ascertained from the makers of the engines, and was shown graphically in Plate 11.

With regard to the theta-phi diagram, in addition to the three papers mentioned by Mr. Cowper (page 110), a description of it would also be found in the second edition of Cotterill's "Steam Engine" (pages 223–30), together with an account of how it was obtained.

The possibility that the figures given for the funnel gas analyses might be vitiated by air leaking in had been suggested by Mr. Phillips (page 112). Where the point at which the chimney temperature had been measured, and at which the samples of the funnel gases had been collected, was high up in the funnel, some leakage of air must of course have crept in; therefore the analysis of funnel gas collected at some height above the boiler must always include a certain amount of air leakage. But he imagined that the quantity of air leaking in could not be large; and the leakage would tend in a measure to correct itself in the calculations, because it would reduce the temperature of the escaping gases. No serious error therefore he thought could have arisen from this cause.

To himself it was a peculiarly interesting coincidence that it should have fallen to his lot to present the first paper read to this Institution during the presidency of Professor Kennedy, when he remembered that their President had been his teacher and his chief, and that it was to him he owed whatever scientific knowledge he possessed. It was still more interesting to recall that this paper was merely a summary of the splendid series of elaborate trials carried out by the Research Committee of this Institution under the chairmanship of their present President; and Professor Kennedy had not merely directed and supervised the whole of the arrangements, but had himself been the very life and soul of the Committee. In expressing how great a debt of gratitude he himself owed to their President, he felt sure he was also expressing the feeling of the

whole profession that they as engineers owed him a similar debt for these important trials, and for the amount of labour and energy he had bestowed upon them as Chairman of the Committee, and for the valuable reports which had been presented to the Institution.

The President, in thanking Professor Beare for what he had just said, could assure him that the feelings he had expressed were most cordially reciprocated by himself. The work of these marine-engine trials, with which he had throughout been connected, had been not only a work of great labour, but also certainly a work of love, on the part of all who had carried them out. While nominally he had himself been at the head of this research, he considered that actually he had been by no means the hardest worker therein; and he was glad to believe that the work done had turned out to be of great practical importance. When this subject was first broached by himself at Leeds (Proceedings 1886, pages 505–8), he well remembered hearing both in public and in private that it was impracticable to carry on any such trials of marine engines without interrupting the whole work of a steamer, and that in fact it was not possible to measure the feed-water at all; the whole notion indeed was regarded as merely academic. Many members of the Institution however did not agree with that view; and the result had been the carrying out of these trials, which he hoped might be the precursors of many others to be conducted in future by shipowners and engine-builders themselves. The Committee's view had been clearly expressed both by Mr. White (page 76) and by Mr. Phillips (page 111), that any comparison of the engines ought to be made entirely in what might be called a scientific sense, and not as a question between different makers, or as though in any case one engine could be pronounced better than another. The matter was far too complicated for any decision of that kind to be arrived at, and it was not desirable that it should be attempted. The Committee were greatly indebted to the shipowners and engineers who had so handsomely placed their ships and engines at their disposal. The thanks of the Institution had

(The President.)

already been given to them, and the Members had had the pleasure on many occasions of seeing them present at their meetings, and hearing what they had to say about the trials.

It was now his pleasant duty to propose that a hearty vote of thanks be given to Professor Beare for preparing the paper which had been read and discussed. This resolution he was sure would be adopted by all the Members with great cordiality.

Capt. H. Riall Sankey, in continuation of his remarks at the meeting (pages 82–91), wrote that, in connection with the $\theta\ \phi$ diagrams for the "Iona," Plate 16, exception had been taken by Mr. Mudd (page 92) to the conclusion arrived at by the writer (page 88) that there was a leaky valve admitting steam into the top of the intermediate cylinder. By means of the cyclogram diagrams Mr. Mudd had himself shown (page 80) that heat was added to the steam in the intermediate receiver; and the $\theta\ \phi$ diagrams fully confirmed this by the admission line of the intermediate cylinder overlapping the exhaust line of the high-pressure, as well as by the considerable improvement in the dryness of the steam. The evidence however as to there being a leaky valve for the steam admission at the top of the intermediate cylinder was afforded by the shape of the $\theta\ \phi$ expansion curve of this cylinder in Plate 16, and had nothing to do with the reheating of the steam in the receiver.

In compliance with Professor Beare's request (page 124), he had had the mean indicator diagrams of the "Colchester" and of the "Fusi Yama" transferred to the $\theta\ \phi$ chart, as shown in Plates 18 and 19. Unfortunately the same could not be done for the "Meteor," because the jacket steam had not been separately measured, and it was therefore not possible to obtain the dryness fraction in each cylinder at some point in the expansion; thus the position of the initial point on the $\theta\ \phi$ chart could not be plotted.

The $\theta\ \phi$ diagrams for the "Colchester," Plate 18, were on the whole similar to those for the "Ville de Douvres," Plate 15. The difference lay in the expansion curves of the high-pressure

cylinders: in the "Colchester" the closeness of this curve to the condensation-water heat-recovery line showed that a considerable quantity of heat had been added to the steam in this cylinder after cut-off; and as there was no jacket, a leak past the valve was a possible explanation. But in this instance another explanation might be given. From the indicator diagrams (1890, Plates 94 and 95) it would be observed that the pressure during admission, especially for the top end of each high-pressure cylinder, was considerably below the boiler pressure. This difference in pressure would impart kinetic energy to the steam on entering the cylinder; a portion of this energy would be re-converted into heat, and would tend to superheat the steam; and the rest would remain as kinetic energy in the form of eddies; and the energy in these eddies would, at any rate partly, reappear as heat during expansion, doing work on the piston. The dryness fraction at cut-off, namely at about 60 per cent. of the stroke, was seen to be practically the same in the high-pressure cylinders of the "Colchester" as in the "Ville de Douvres;" but the total range of temperature was somewhat greater in the latter. As read off the θ ϕ diagrams by means of the temperature scale, the range in the "Ville de Douvres" was from 334° down to 248°, or 86 degrees; and for the "Colchester" from 310° down to 234°, or 76 degrees. The range of temperature to which the admission surface was exposed was seen to be less in the "Ville de Douvres," namely from 334° down to 324° or 10 degrees, as compared with 310° down to 264° or 46 degrees in the "Colchester." On these grounds therefore greater initial condensation was to be expected in the "Colchester"; but the higher speed of revolution in this steamer, namely 86·5 revs. per minute as against 36·8 in the "Ville de Douvres," was probably the principal cause of the condensation being about the same in both. The superheating already mentioned no doubt contributed also to this result. The loss in the high-pressure cylinder due to incomplete expansion was as noticeable in the "Colchester" as in the "Ville de Douvres"; a portion however of this loss was recovered in the low-pressure cylinders of both steamers, as was clearly shown in the θ ϕ diagrams by the marked improvement in the dryness fraction at cut-off in the

(Capt. H. Riall Sankey.)
low-pressure cylinders of both engines: an improvement due to the kinetic energy imparted to the steam at release from the high-pressure cylinder, which formed eddies and reappeared partially as heat in the low-pressure cylinder.

The θ ϕ diagrams for the "Fusi Yama," Plate 19, were in marked contrast with those for the "Colchester" and the "Ville de Douvres." The dryness fraction at cut-off in the high-pressure cylinder was remarkably high, namely 89·5 per cent., and considerably higher than could have been expected even with the smaller range of temperature, namely from $298\frac{1}{2}°$ down to 235° or $63\frac{1}{2}$ degrees, especially as this cylinder was not jacketed. The most striking point of difference however was the considerable falling off in the dryness of the steam in the low-pressure cylinder, instead of the improvement in the "Colchester" and the "Ville de Douvres." It would also be observed that there was a great difference of pressure between the exhaust of the high-pressure cylinder and the admission of the low-pressure. This, together with the reduction in the dryness fraction, suggested a leak from the valve-chest of the low-pressure cylinder into the exhaust; and an examination of the sectional plan (1890, Plate 105) showed that such a leak was quite possible.

In order to check the accuracy with which the indicator diagrams had been transferred to the θ ϕ chart, the heat units turned into work by each engine had been calculated from the θ ϕ diagrams as follows. The area of each θ ϕ diagram having been ascertained by the planimeter, the corresponding heat units could at once be obtained, the number of thermal units represented by one square inch of the chart being known; and these heat units were marked against each of the θ ϕ diagrams given in Plates 15 to 19. The volume-factor was also marked for each diagram. By multiplying these heat units by the corresponding volume-factor, the heat units accounted for per stroke in each cylinder were obtained, and were given in line 3 of the accompanying Table 36. A glance at lines 4 to 7 of the table would show how thence to obtain the heat units turned into work per minute by each engine; and line 8 gave for comparison the corresponding figure taken from Table 29 (page 60); it would be seen that the agreement was as close as could be expected.

TABLE 36.—*Heat turned into Work, as calculated from θ φ diagrams.*

See Plates 15 to 19.

Name of Steamer	"Tartar."			"Iona."			"Colchester."		"Fusi Yama."		"Ville de Douvres."	
Plate showing θ ϕ diagrams	Plate 17.			Plate 16.			Plate 18.		Plate 19.		Plate 15.	
Cylinder — High-pressure, Intermediate, or Low-p.	High	Inter	Low	High	Inter	Low	High	Low	High	Low	High	Low
1. Heat in θ ϕ diagrams, Th. U.	26·4	41·0	46·0	44·3	54·0	63·0	52·3	57·5	50·0	58·4	48·5	50·7
2. Volume-factor ratio	3·435	3·020	2·640	1·630	1·450	1·220	2·260	2·180	1·288	1·303	18·16	17·01
3. Heat per stroke Th. U.	90·68	123·82	121·44	72·21	78·30	76·86	118·19	125·35	64·40	76·09	881	862
4. Heat per revolution Th. U.	181·36	247·64	242·88	144·42	156·60	153·72	236·38	250·70	128·80	152·19	1762	1724
5. Heat per revolution, total for engine Th. U.	671·88			454·74			487·08		280·99		3486	
6. Revolutions per minute	70 revs.			61·1 revs.			86·0, 87·1 } 86·55		55·59 revs.		36·82 revs.	
7. Heat per minute, total for engine Th. U.	47,032			27,765			Two engines 84,314		15,620		128,354	
8. Heat per minute, total for engine, as given in Table 29 Th. U.	46,490*			27,590			84,630		15,870		127,300	

* From Proceedings 1890, page 240, Table 6, line 56.

(Capt. H. Riall Sankey.)

He hoped he had succeeded in showing that, by this method of transferring the indicator diagrams of any engine to the $\theta\ \phi$ chart, valuable information as to the behaviour of the steam might be obtained. Moreover the various losses might be traced to the places of their occurrence, and their magnitude exhibited; then by reference to the design or construction of the engine the cause of these losses might be ascertained. Besides the few points to which he had called attention in relation to the expansion curves and the release, many other questions of interest arose in connection with the admission, exhaust, and compression lines. For the calculations required in transferring the indicator diagrams to the $\theta\ \phi$ chart he was indebted to his assistant, Mr. H. O. Beckh.

Mr. W. R. Cummins wrote that, in summarizing the results of the six trials carried out by the Institution, Professor Beare had separated the efficiency of the boilers from that of the engines. Since the amount of priming was measured in only the one instance of the "Ville de Douvres," and this measurement was made by means of the salt test, about the accuracy of which doubts have been raised, the absolute accuracy of the boiler efficiency cannot be relied upon. The possible error in the efficiency is measured by the possible amount of priming; and as this may amount to as much as 20 per cent. of the total feed, and may not be suspected at the trial, the heat balance-sheet should be taken with a certain amount of reserve. For instance, the amount debited to radiation is dependent for its accuracy upon the assumption that the whole of the feed-water was turned into steam. By separating the efficiency of the boilers and engines, and neglecting possible priming, the boiler efficiency may be exalted at the expense of the engine efficiency. One of the most significant results obtained from these trials is contained in Table 18 in the line showing the carbon-value of the fuel per indicated horse-power per hour: though this does not separate the efficiency of the boilers from that of the engines. On re-arranging these carbon-values in connection with the boiler pressure and the ratio of expansion, as in the accompanying Table 37, it is seen at a glance how the efficiency runs up with increased pressure and

TABLE 37.—*Boiler Pressure, Expansion, and Carbon-value of fuel.*

Steamer.	Boiler Pressure absolute.	Expansion. Number of times.	Carbon-value per I.H.P. per hour.
	Lbs. per sq. inch.		Lbs.
Iona . .	179·58	19·0	1·49
Meteor . .	160·10	10·6	1·76
Tartar . .	158·20	15·7	1·82
Ville de Douvres	120·64	5·7	2·30
Fusi Yama .	71·64	6·1	2·33
Colchester .	95·50	6·1	2·65

expansion. Even the "Tartar" with so much water in the cylinders is 30 per cent. more economical than the "Colchester."

With regard to the increase in weight of steam after cut-off in the high-pressure cylinder of the "Tartar," suspicion naturally falls first upon the piston-valve. The piston itself is also mentioned by the author (page 47) as possibly leaking too; but obviously, if the piston were leaking, the weight of steam should become less, inasmuch as during expansion the other side of the piston is open to the exhaust. If the piston-valve on the high-pressure cylinder was fitted with a solid ring, it would be quite capable of passing steam after slight wear.

If leakage is out of the question, the only reasonable alternative is re-evaporation, for which the heat required could come only from the cylinder walls: that is to say, it would be heat that had been stored in the walls by initial condensation. It may further be readily supposed that wet steam would absorb heat from metallic surfaces more quickly than dry steam. Under ordinary conditions the re-evaporation of the initially condensed steam would not be finished until compression began in the return stroke; but with wetter steam the greater part of the re-evaporation might possibly take place during the period of expansion. There is no difficulty about time, inasmuch as the whole of the condensation

(Mr. W. R. Cummins.)

takes place during the period of admission, which in the case of the "Tartar" is about the same as the period of expansion. The great amount of water noted in the intermediate cylinder of the "Tartar" the author thinks (pages 47–9) can be explained by initial condensation in the high-pressure cylinder, apart altogether from priming; the film of water deposited on the high-pressure cylinder surfaces, and not entirely re-evaporated owing to the jacket not being in use, he says would eventually be carried into the intermediate cylinder. This seems to the writer to be highly improbable. For condensation and re-evaporation must exactly balance each other, provided the engines are working under steady conditions; the whole of the steam condensed during admission must be re-evaporated before compression begins; and this action is quite independent of the steam-jacket. If at the end of each stroke some of the initially condensed steam were to remain not re-evaporated, then the cylinder walls would be accumulating heat in each successive stroke. Hence it follows that the only water which can be delivered from the high-pressure cylinder to the intermediate is that due to priming, and to the liquefaction consequent upon the performance of the work done, and to any condensation resulting from radiation. The most rational explanation therefore of the "Tartar" results appears to the writer to be that, owing to excessive priming and consequent wetness of steam, nearly the whole re-evaporation of the initially condensed steam took place during the expansion; and also that the priming water, as well as that due to liquefaction by work, was transferred into the intermediate cylinder.

When treating of the effects of steam-jackets and re-evaporation (pages 63–5), the author gives weights of steam as present in the cylinder at certain points in the stroke. The weight given however is not the actual weight present in the cylinder alone at the point named, but is the weight of steam passing through the cylinder as measured from the indicator diagram; that is to say, it is the actual weight of steam present in the cylinder at the point named, including clearance as in Table 31, but minus the weight of steam present in the cylinder and clearance when the pressure in the return stroke has risen by compression to the same pressure as that at the point named

in the steam stroke. The expression "present in the cylinder" is apt to be misleading without this explanation. When this method of estimating the weight of steam in the cylinder is applied to testing the amount of re-evaporation during expansion, a correct result can be obtained only when the weight of steam shut in by compression does not vary during the period of compression. The only reliable method of arriving at the re-evaporation during expansion is to calculate the actual weight of steam present just after cut-off, and to compare it with the actual weight present just before release. No doubt this method would considerably modify the author's figures, if it has not been followed in Table 31. If it has, then for the "Tartar" it will be necessary to fall back upon the explanation already attempted. In Table 32 it is evident that all the percentages there given represent steam passing through the cylinder as calculated from the indicator diagrams; and this must be duly allowed for before drawing any conclusions as to the actual amount of cylinder condensation and the relative weight of steam in each cylinder.

To arrive at the actual weight of steam condensed initially in a cylinder is no easy matter; and if no tests for priming have been made, accuracy is out of the question. Starting at the point of compression beginning, there is a known weight of steam shut in, which remains in the cylinder until release. With this steam will in most cases be mixed a certain amount of water; and the only way to test the amount is to apply a calorimeter to the exhaust. Failing this, it must be estimated from the priming water and the water of liquefaction. The weight of the mixture of steam and water must be added to the weight of feed-water per stroke, after subtracting from the latter the weight supplied to steam-jackets if any; the net sum is then the total weight of mixture present in the cylinder after cut-off. The actual weight of steam present in the mixture just after cut-off can be calculated from the indicator diagram; the water constituting the balance must either have been condensed in the cylinder initially or supplied to the cylinder as water. The quantity supplied to the cylinder as water is tested by the calorimeter; and the remainder must therefore have been condensed initially on the clearance and cylinder surfaces. This last quantity is the total

(Mr. W. R. Cummins.)

weight condensed; that is, it results from the condensation of the clearance steam as well as of the new steam supplied in each stroke. The amount of clearance steam condensed can be calculated from the indicator diagram by comparing the weights at the beginning and the end of compression. It will then be known what proportion of the new steam supplied to the cylinder has been condensed; and this appears to be what should be called "initial condensation." With this definition the figures given in Table 32 do not correspond. Furthermore, when comparing weights of steam in two different cylinders—for example (Table 32) in the "Iona" 65·5 per cent. of total feed in the high-pressure cylinder before release and 74·9 per cent. in the intermediate cylinder before release—it might be imagined from these figures that there was 14 per cent. more steam in the intermediate cylinder than there ought to be; whereas the seeming difference is due solely to the method of estimating the weights, and to the fact that there was more compression in the high-pressure cylinder than in the intermediate.

Mr. DRUITT HALPIN wrote that in the discussion of M. Marié's paper on the consumption of fuel in locomotives (Proceedings 1884, page 111) he had suggested a "figure of merit," by which the total efficiency of boilers might be measured:—namely the product of the weight of water evaporated per hour per square foot of heating surface, which measured the rapidity of evaporation, multiplied by the weight of water evaporated per pound of fuel, from and at 212° Fahr. in both cases. If however, instead of being multiplied by the evaporation per pound of fuel, which did not take into account the calorific value of the fuel, the weight of water evaporated per hour per square foot of heating surface was multiplied by the percentage of heat in the fuel taken up by the feed-water, the following results were obtained from Table 18 (page 39):—

	Meteor.	Colchester.	Fusi Yama.	Iona.	Ville de Douvres.
Evaporation per hour per square foot of heating surface . .	4·49	7·39	3·48	2·73	9·02
Percentage of heat in fuel taken up by feed-water . . .	62·0	62·0	67·2	69·2	66·1
Total efficiency of boilers . .	278	458	234	189	596

Professor BEARE wrote that he desired again to thank Capt. Sankey for the great amount of time and trouble he had taken in preparing the $\theta \phi$ diagrams, and for the valuable and interesting explanation he had given of their construction from the indicator diagrams, and of their use in discovering defects in the working of engines. For instance the $\theta \phi$ diagrams of the "Iona" were interesting, as showing that the increased dryness-fraction in the intermediate cylinder, referred to in page 63, was in all probability due to a leaky valve.

The remark as to leakage past the piston in the "Tartar" (page 47) was a slip, to which attention had been drawn by Mr. Cummins (page 135). In regard to initial condensation, radiation seemed to have been forgotten in the remark (page 136) that all the steam condensed in the cylinder must be re-evaporated before the end of the release, or else the cylinder walls would accumulate heat: although reference was made a little later to radiation producing condensation. It was well known that in unjacketed cylinders a large proportion of the heat given up to the walls during initial condensation was radiated away by the walls, and that therefore initial condensation and re-evaporation by no means balanced each other; the same action occurred even in jacketed cylinders, because the jacketing was never perfect. The assumption therefore that only priming water, and steam liquefied by doing work, passed into the intermediate cylinder, could hardly be considered as accurate. In the calculations given in Table 31, as stated in page 64, the figures were the actual weights of steam in the cylinder and clearance, without any deduction for weight of steam shut up in compression; the criticism in pages 136–7 seemed therefore hardly to apply. Table 32 had been compiled from the several reports, and was the usual way in which such figures were given.

ON THE SURFACE CONDENSATION OF STEAM.

BY LT.-COLONEL THOMAS ENGLISH.

In the course of a series of trials made for the Direct Measurement of Initial Condensation in a Compound Steam-Engine,* the author has been led to the conclusion that the condensation of steam on a metallic surface is in all cases governed by the thermal resistance of the film of water deposited by the condensation of the steam itself. The rate of condensation varies directly as the difference of temperature between the two surfaces of this film, and inversely as its thickness; and there is no difference between the thermal resistance of the surface of the metal and that of its interior substance. The present paper includes an account of the trials referred to, and a comparison of their results with calculations based on the author's conclusions; together with the explanation, by similar calculations, of the results of experiments by other enquirers into the subjects of surface condensation and evaporation.

Engine.—The engine on which these trials were made was built by Messrs. B. Donkin and Co. in 1890, and is in use at Palmer's Ordnance Works, Jarrow. As shown in the general plan, Fig. 1, Plate 20, it consists of a high-pressure and a low-pressure cylinder set horizontally side by side, and connected to cranks at right angles to each other on the shaft, with the fly-wheel between them. The high-pressure cylinder is 20 inches diameter, and the low-pressure $32\frac{1}{2}$ inches, and the stroke of each is 48 inches.

Valves.—Each cylinder is fitted with separate steam and exhaust valves of the Sulzer kind, the high-pressure steam-valves being

* Previous papers by the author on Condensation in Steam-Engine Cylinders are printed in the Proceedings, 1887 page 503, 1889 page 641, and 1892 page 198.

controlled by the governor through trip gear which allows of separate adjustment of the beginning and of the end of the steam admission, Figs. 2 and 3, Plate 21. The valves are all of double-beat pattern with vertical spindles; the steam valves are on the top of each cylinder at the ends, opening upwards, and the exhaust valves directly below them, also opening upwards. Motion is given to the valve spindles, through levers and connecting rods, by cams on a separate revolving shaft S for each cylinder, parallel to the axis, and connected by mitre wheels to the crank shaft. The cams which lift the steam valves of the low-pressure cylinder are capable of being set so as to vary the point of cut-off. A relief valve $2\frac{1}{4}$ inches diameter, kept shut by a spiral spring, is fitted at each end of each cylinder.

Jacketing.—Both cylinders are jacketed on the barrel by the working steam, which has to circulate round the cylinder before it enters through the steam valves. The barrel jacket is prolonged six inches beyond each end of the cylinder; and the cylinder ends are further jacketed by cavities cast in them, communicating with the prolongation of the barrel jacket through four holes of half-inch diameter, two at the top and two at the bottom.

Auxiliary Valve-Gear.—The trials are designed to weigh the steam required to fill the clearance at the commencement of each stroke, separately from that which enters the cylinder after the piston begins to move. For this purpose the end of the high-pressure cylinder farthest from the crank was selected; and an auxiliary valve-gear, independent of the ordinary steam-admission, was fitted, by which the steam to fill the clearance is supplied from a separate boiler of an 8-HP. portable engine, through a 2-inch pipe $37\frac{1}{2}$ feet long and lagged throughout, to a double-beat valve V, Figs. 2 and 3, Plate 21, $4\frac{1}{2}$ inches diameter with a vertical spindle. This valve is fitted as close as possible to the cylinder, and opens into it through the seating of the relief valve, which is temporarily removed. At each revolution of the engine the valve spindle is lifted through a bent lever L, by an adjustable cam C secured to the revolving shaft S which drives the main valve-gear, as shown in Figs. 2 and 3. This double-beat valve is closed by its own steam

acting on four square inches of unbalanced area, and aided by an india-rubber spring R. In order to give as sharp a cut-off as possible to this auxiliary valve, it is made to lift as much as half an inch by the action of the cam, although a lift of only 0·15 inch gives an opening equal to the area of the 2-inch steam-pipe. The cam is adjusted to open the auxiliary valve at any desired point during the period of compression, and to close on the dead centre; whilst the main steam-valve is adjusted to open at the dead centre, and thus to continue the supply of steam to the cylinder. The combined action of the two valves produces an indicator diagram which cannot be distinguished from the diagram drawn when using the main valve-gear alone, adjusted in the ordinary way.

Measurement of Initial Condensation.—By weighing the amount of water evaporated in the auxiliary boiler for a known number of strokes, it becomes possible by this arrangement to ascertain directly the amount of steam expended per stroke, partly in initial condensation, and partly in increasing the pressure in the clearance from that due to the cushion steam; and by adding to the weight thus found the weight of cushion steam, and deducting the weight of saturated steam required to fill the clearance at the pressure existing when the main valve opens, a direct measure is obtained of the weight condensed in the time required to fill the clearance.

The weight of cushion steam and the weight of saturated steam required to fill the clearance space of 0·782 cubic foot can be readily calculated from measurements of the mean steam-pressure on the indicator diagrams. The indicator gear is arranged either to take diagrams in the ordinary way, or to be connected to the crank of the low-pressure cylinder. In the latter case, the pressures which occur at the ends of the stroke are transferred to the middle of the diagram; and the horizontal distances representing on the diagram the motion of the piston near the ends of the stroke are sufficiently elongated to show clearly the intervals between the various changes. Immediately after taking a diagram in this manner, the governor is lifted by hand for a few revolutions, which causes the trip gear to miss

lifting the main steam-valve: whereby is produced on the same paper a diagram of the steam passing through the auxiliary valve alone. The combined diagram thus obtained, Plates 22 to 30, is employed to determine a scale for the time occupied in the observed condensation, by measuring on it the horizontal distance between the point corresponding with the moment of admission through the auxiliary valve, and the point at which the two curves diverge. This horizontal distance bears approximately the same proportion to the product of $\pi \times$ total length of diagram, as the time elapsed from the commencement of admission bears to the total time of a revolution. The weight of steam condensed in this time, multiplied by its latent heat, and divided by the area of clearance surface, 13·98 square feet, gives the number of thermal units set free by condensation on each square foot; and the mean rate of condensation per square foot per minute can be determined therefrom, when the actual time occupied in condensation has been calculated.

In order to ascertain accurately the weight of water supplied to the auxiliary boiler, its feed-pump is driven from shafting, and the tub from which it draws its supply is mounted on a one-ton weighing machine. The auxiliary boiler is pumped up while cold to a marked level on the gauge glass; steam is then raised, and all feed-water weighed into the boiler. After the boiler has cooled down again on the conclusion of a trial, sufficient water is either pumped in or taken out to bring the water-level to the same mark on the gauge glass; and the weight thus required is added to or deducted from the weight of feed-water previously observed. A correction, ascertained by trial, of 14 lbs. per hour, is also applied to allow for imperceptible leakage whilst the boiler is under steam.

Results of Trials.—The mean results of each of the trials are detailed in the appended Table 22, lines 1 to 22, omitting those trials in which doubt existed as to the accuracy of any of the measurements. For each trial detailed the indicator diagrams nearest to the mean are shown, both from the low-pressure crank and also the ordinary diagram, and both for the main steam and for the auxiliary-valve steam; these are shown in Plates 22 to 30. The

(*continued on page* 148.)

TABLE 22 (*continued to page* 147).

Results of Trials for direct measurement of

Initial Condensation in a Compound Engine.

1	Date of trial	1893	Feb. 3
2	Number of trial	No.	3
	See Diagrams	*Plates*	22,31
3	Duration of trial	minutes	208¼
4	Number of revolutions during trial	revs.	13,845
5	Total weight of feed water to auxiliary boiler	lbs.	1,111
6	Deduction for leakage at rate of 14 lbs. per hour	lbs.	48·5
7	Net steam supply during trial	lbs.	1,062·4
8	Barometer height, inches of mercury	inches	30·3
9	Pressure p_o of steam filling clearance, lbs. per sq. inch	lbs.	32·3
10	Density ρ_o of steam filling clearance, lb. per cub. foot	lb.	0·080
11	Weight W_o of steam filling clearance	lb.	0·0625
12	Pressure p_c of cushion steam, lbs. per sq. inch	lbs.	20·7
13	Density of cushion steam, lb. per cub. foot	lb.	0·053
14	Weight W_c of cushion steam	lb.	0·0414
15	Weight W_a of net steam supply per revolution	lb.	0·0768
16	Observed total weight of steam and water in clearance, $W_o + w_o$	lb.	0·1182
17	Observed weight w_o of steam condensed per stroke	lb.	0·0557
18	Observed weight condensed ÷ observed total weight	ratio	0·471
19	Initial temperature t_b of steam from auxiliary boiler	Fahr.	293°
20	Temperature of steam at observed pressure p_o	Fahr.	254°
21	Temperature t_c of steam at observed cushion pressure p_c	Fahr.	230°
22	Latent heat L of steam at initial temperature t_b	th. units	908
23	Calculated difference of temperature of surfaces of water film deposited, $t_o - t_z$	Fahr.	37°
24	Calculated difference of surface temperatures of metal, $t_z - t_y$	Fahr.	26°
25	Calculated time s of condensation	second	0·0303
26	Calculated depth y of metal affected	inch	0·056
27	Calculated thickness z of water film deposited	inch	0·0008
28	Calculated mean rate of condensation per square foot per minute, $60\,U \div s$	thermal units	7,160

(continued on next page) TABLE 22.

Results of Trials for direct measurement of

Initial Condensation in a Compound Engine.

Feb. 8 4 22,31	Feb. 21 6 23,32	Feb. 28 7 23,32	Mar. 7 8 24,33	Mar. 14 9 24,33	Mar. 16 10 25,34	Mar. 27 12 25,34	Apr. 13 14 26,35	1 2
212	210	150	150	153	150	150	150	3
14,050	14,324	9,978	10,188	10,278	9,980	9,954	9,954	4
1,031·5	1,003	871·5	951	933·5	998	956·25	965·75	5
49·5	49	35	35	35·75	35	35	35	6
982	954	836·5	916	897·75	963	921·25	930·75	7
29·9	29·4	29·7	30·3	29·9	29·6	30·3	30·5	8
28·6	28·6	32·0	30·0	30·0	35·1	29	28	9
0·071	0·071	0·079	0·075	0·075	0·086	0·072	0·070	10
0·0555	0·0555	0·0618	0·0586	0·0586	0·0672	0·0563	0·0547	11
17·3	19·2	20·9	19·3	18·7	22·2	14·3	14·3	12
0·045	0·049	0·054	0·049	0·048	0·056	0·038	0·038	13
0·0352	0·0383	0·0422	0·0383	0·0375	0·0438	0·0297	0·0297	14
0·0699	0·0666	0·0839	0·0899	0·0874	0·0965	0·0926	0·0936	15
0·1051	0·1049	0·1261	0·1282	0·1249	0·1403	0·1223	0·1233	16
0·0496	0·0494	0·0643	0·0696	0·0663	0·0731	0·0660	0·0686	17
0·472	0·471	0·510	0·543	0·531	0·521	0·540	0·556	18
293°	293°	308°	308°	308°	308°	308°	308°	19
247°	247°	254°	250°	250°	259°	248°	246°	20
220°	226°	230°	226°	224°	234°	211°	211°	21
908	908	897	897	897	897	897	897	22
45°	40°	49°	52°	53°	46°	64°	64°	23
28°	27°	29°	30°	31°	28°	33°	33°	24
0·0199	0·0221	0·0306	0·0336	0·0295	0·0419	0·0245	0·0265	25
0·045	0·048	0·056	0·059	0·055	0·066	0·050	0·052	26
0·0007	0·0007	0·0010	0·0010	0·0010	0·0010	0·0010	0·0010	27
9,690	8,690	8,100	7,980	8,650	6,710	10,350	9,960	28

TABLE 22 (*continued from preceding page*).

Results of Trials for direct measurement of

Initial Condensation in a Compound Engine.

1	Date of trial	1893	Apr. 14
2	Number of trial	No.	15
	See Diagrams	*Plates*	26,35
3	Duration of trial	minutes	150
4	Number of revolutions during trial . . .	revs.	9,917
5	Total weight of feed water to auxiliary boiler . .	lbs.	952·25
6	Deduction for leakage at rate of 14 lbs. per hour .	lbs.	35
7	Net steam supply during trial	lbs.	917·25
8	Barometer height, inches of mercury . . .	inches	30·3
9	Pressure p_o of steam filling clearance, lbs. per sq. inch	lbs.	26·8
10	Density ρ_o of steam filling clearance, lb. per cub. foot	lb.	0·067
11	Weight W_o of steam filling clearance . . .	lb.	0·0524
12	Pressure p_c of cushion steam, lbs. per sq. inch . .	lbs.	13·5
13	Density of cushion steam, lb. per cub. foot . .	lb.	0·036
14	Weight W_c of cushion steam	lb.	0·0281
15	Weight W_a of net steam supply per revolution . .	lb.	0·0926
16	Observed total weight of steam and water in clearance, $W_o + w_o$	lb.	0·1207
17	Observed weight w_o of steam condensed per stroke .	lb.	0·0683
18	Observed weight condensed ÷ observed total weight	ratio	0·566
19	Initial temperature t_b of steam from auxiliary boiler .	Fahr.	308°
20	Temperature of steam at observed pressure p_o . .	Fahr.	244°
21	Temperature t_c of steam at observed cushion pressure p_c	Fahr.	208°
22	Latent heat L of steam at initial temperature t_b	th. units	897
23	Calculated difference of temperature of surfaces of water film deposited, $t_o - t_z$	Fahr.	66°
24	Calculated difference of surface temperatures of metal, $t_z - t_y$	Fahr.	34°
25	Calculated time s of condensation	second	0·0254
26	Calculated depth y of metal affected . . .	inch	0·051
27	Calculated thickness z of water film deposited . .	inch	0·0010
28	Calculated mean rate of condensation per square foot per minute, $60\ U \div s$	thermal units	10,360

(*concluded from page* 144) TABLE 22.

Results of Trials for direct measurement of

Initial Condensation in a Compound Engine.

Apr. 17	Apr. 18	Apr. 20	Apr. 28	Apr. 29	May 15	May 25	June 1	1
16	17	18	22	23	24	25	26	2
27,36	27,36	28,37	28,37	29,38	29,38	30,39	30,39	
150	150	150	150	150	150	150	150	3
10,158	9,969	9,884	9,946	9,871	4,561	4,850	4,804	4
905	927·25	910	1,006	990·25	668·25	686·50	723	5
35	35	35	35	35	35	35	35	6
870	892·25	875	971	955·25	633·25	651·50	688	7
30·4	30·3	30·2	30·1	30·1	30·2	29·9	29·9	8
30·3	29·1	27·3	30·1	29·5	38·1	28·9	35·4	9
0·076	0·073	0·069	0·076	0·074	0·094	0·072	0·087	10
0·0594	0·0571	0·0540	0·0594	0·0578	0·0735	0·0563	0·0682	11
20·9	16·7	14·3	16·7	15·5	13·6	10·3	13·3	12
0·054	0·043	0·038	0·043	0·040	0·036	0·027	0·035	13
0·0422	0·0336	0·0297	0·0336	0·0313	0·0281	0·0211	0·0274	14
0·0856	0·0896	0·0886	0·0976	0·0968	0·1388	0·1343	0·1432	15
0·1278	0·1232	0·1183	0·1312	0·1281	0·1669	0·1554	0·1706	16
0·0684	0·0661	0·0643	0·0718	0·0703	0·0934	0·0991	0·1024	17
0·535	0·536	0·543	0·547	0·549	0·560	0·637	0·602	18
308°	308°	308°	308°	308°	308°	308°	308°	19
251°	249°	245°	251°	249°	264°	248°	260°	20
230°	218°	211°	218°	215°	208°	195°	207°	21
897	897	897	897	897	897	897	897	22
49°	58°	64°	58°	60°	66°	76°	67°	23
29°	32°	33°	32°	33°	34°	37°	34°	24
0·0346	0·0271	0·0233	0·0319	0·0293	0·0474	0·0461	0·0564	25
0·059	0·053	0·049	0·057	0·055	0·070	0·069	0·076	26
0·0010	0·0010	0·0010	0·0011	0·0011	0·0014	0·0015	0·0015	27
7,610	9,400	10,620	8,650	9,220	7,570	8,270	6,980	28

ordinates marked on each pair indicate simultaneous angular positions in the revolution of the crank-shaft; but the two diagrams in each pair, not being taken simultaneously, do not necessarily correspond exactly.

In line 9 of the Table, the pressure p_o of steam filling the clearance space is that marked in diagram 3, Plate 22, measured from zero to the point at which the diagram representing the steam admitted through the auxiliary valve alone diverges from that representing the steam admitted through both valves; for it is evident that, even if the auxiliary valve were not closed at this point, no more steam could enter through it against the increasing pressure of the steam admitted through the main valve.

In line 12, the pressure p_c of cushion steam is measured from zero, as shown in diagram 3, Plate 22, to the point at which the compression curve changes its direction owing to the admission of the steam through the auxiliary valve.

Each trial in which the conditions have been varied has been repeated a sufficient number of times to ensure that similar results, within reasonable limits of error of observation, would follow a further repetition. The trials show that an amount of heat may be set free which will correspond with a mean rate of initial condensation of from 6,700 to 10,600 thermal units per square foot per minute.

If it be assumed that the clearance surface is dry before admission, the possible rate of condensation will vary directly as the difference between the temperatures of the two surfaces of the film of water deposited by the condensation itself, and inversely as its thickness; the rate must therefore be exceedingly rapid at first, and immediately diminish. The amount of heat observed to be set free may be accounted for as being absorbed by the metal, following generally the method of calculation adopted by Professor Cotterill in "The Steam Engine," (second edition, page 278); but it is necessary to change the supposition (page 284) that the surface temperature of the metal on the admission of steam follows a harmonic cycle, into a supposition that it is the same as that of the adjoining surface of the water film. It is also necessary to make some supposition

as to the variation of temperature in the interior of the metal; and the author has chosen the assumption of a constant difference between the surface temperature and that of the metal immediately beyond the surface layer affected, as probably near the truth during the time of condensation. It will be shown that on these assumptions the results from the indicator diagrams can be brought into satisfactory accordance with calculation based on the known laws of conductivity.

The amount of heat available per square foot is measured by the weight of the film of water deposited, multiplied by its latent heat at the temperature at which condensation commences. The small amount of heat set free by the cooling of the film is neglected; and therefore the flow of heat at any instant through the film is taken to be equal to the flow into the metal at the same time. The heat passing into the metal is considered to be entirely absorbed in raising the temperature of the surface layer, under the condition that the difference between the surface temperature and the temperature of any point in the surface layer which is receiving heat will vary with the depth of the point beneath the surface. This implies that the thermal gradient through the surface layer at any instant has a uniform inclination, but that this inclination decreases throughout from instant to instant. Similarly the difference between the temperature of the surface of the film of water next the steam, and the temperature of any point within the film, is assumed to vary with the depth measured from the surface next the steam.

The auxiliary-boiler pressure was kept at 60 lbs. absolute per square inch in trials Nos. 3, 4, and 6, and at 75 lbs. absolute in the remainder; and the initial temperature t_b of the steam filling the clearance (line 19) has been taken as that due to the auxiliary-boiler pressure. If t_z be the temperature of the common surface of the film of water and of the metal at any time; and if t_y be the temperature at the same time of the metal immediately beyond the interior boundary of the surface layer of thickness y, which has received heat up to this time; and if t_o be the temperature to which the steam has fallen, owing to the condensation:—then $t_o - t_z$ will be the difference of temperature between the two surfaces of the film of water, and $t_z - t_y$

will be the difference of surface temperatures produced in the metal. Taking the average results of experiments on conductivity in iron from Cotterill (page 278), it has been found that, if F be the flow of heat through the surface per square foot per second,

$$F = \frac{7 \cdot 5}{60} \times \frac{d(t_z - t)}{dy}$$

where y is measured in inches. Hence if U be the number of thermal units which have passed through a square foot of the surface in s seconds, with the assumptions made

$$\frac{d(t_z - t)}{dy} = \frac{t_z - t_y}{y}$$

$$\text{and} \quad \frac{dU}{ds} = F = 0 \cdot 125 \times \frac{t_z - t_y}{y} \quad . \quad . \quad . \quad (1)$$

Taking the conductivity of water as $0 \cdot 01$ that of iron, if z be the thickness measured in inches of the film of water which has been deposited, the flow of heat through it

$$\frac{dU}{ds} = F = 0 \cdot 01 \times \frac{7 \cdot 5}{60} \times \frac{d(t_o - t)}{dz}$$

$$= 0 \cdot 00125 \times \frac{t_o - t_z}{z} \quad . \quad . \quad . \quad (2)$$

For cast-iron weighing 450 lbs. per cubic foot, or $37 \cdot 5$ lbs. per each inch in thickness of a plate one foot square, with a specific heat of $0 \cdot 13$,

$$\frac{dU}{dy} = 37 \cdot 5 \times 0 \cdot 13 \times \text{mean rise of temperature}$$

$$= 4 \cdot 875 \times \frac{t_z - t_y}{2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Also if w is the weight of a cubic foot of water in pounds, $\frac{1}{12}\, w\, z$ will be the weight in pounds per square foot of the film of condensed water, and

$$U = \frac{1}{12}\, w\, z\, L \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where L is the latent heat corresponding to the temperature t_b.

From equations (1) and (3)

$$\frac{ds}{dy} = 19 \cdot 5\, y$$

$$\text{and} \qquad y = 0 \cdot 32\, \sqrt{s} \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

or the depth of metal affected varies as the square root of the time, and the conditions determining the flow of heat in the metal will be satisfied by an equation of the form

$$\frac{y}{0 \cdot 32 \sqrt{s}} = \frac{t_z - t}{t_z - t_y}.$$

From equations (1) (2) and (5)

$$t_o - t_z = \frac{100}{0 \cdot 32} (t_z - t_y) \frac{z}{\sqrt{s}} \quad . \quad . \quad . \quad (6)$$

From (1) (4) and (5)

$$\frac{1}{12} w L \frac{dz}{ds} = \frac{dU}{ds} = \frac{0 \cdot 125}{0 \cdot 32} \times \frac{t_z - t_y}{\sqrt{s}}.$$

Hence $\quad \frac{1}{12} w L z = \frac{0 \cdot 125}{0 \cdot 32} \times (t_z - t_y) \times 2 \sqrt{s}$

$$\text{or } z = \frac{3}{0 \cdot 32} \frac{(t_z - t_y)}{w L} \sqrt{s} \quad . \quad . \quad . \quad . \quad (7)$$

From (4) and (7)

$$\left.\begin{array}{l}\text{Mean rate of condensation}\\ \text{in thermal units per}\\ \text{square foot per minute}\end{array}\right\} = \frac{60 U}{s} = 46 \cdot 85 \frac{(t_z - t_y)}{\sqrt{s}} \quad . \quad (8)$$

From (6) and (7) $\quad t_o - t_z = 2925 \frac{(t_z - t_y)^2}{w L},$

$$\text{or } t_o - t_y = t_z - t_y + 2925 \frac{(t_z - t_y)^2}{w L} \quad . \quad . \quad (9)$$

From given values of t_b and t_c, to which the values of t_o and t_y at the commencement of condensation are assumed respectively to be equal, the calculated value of the rise of surface temperature of the metal $(t_z - t_y)$ can be found by equation (9), and is given in line 24 of the table; and this being known, the values of y, z, and U can be determined for successive increments of s.

To connect these equations with the observed results, and determine the value of s for each trial: if w_o be the weight of the film of water which has been deposited up to any time s,

$$w_o = \frac{1}{12} w \times \text{square feet of surface} \times z$$

and by equation (7)

$$w_o = 10 \cdot 92 \frac{t_z - t_y}{L} \sqrt{s} \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

The value of s corresponding to the observed value of w_o can be obtained from this equation; and a curve can be drawn whose abscissæ represent a scale of time, and ordinates a scale of density, which will give the diminution of density of the remaining steam, caused by condensation, for successive increments of s. By the help of a table of the properties of steam, this curve can be transformed into one whose abscissæ represent a scale of time, and ordinates a scale of temperature. If the combined indicator diagram, in which the pressures have been converted to the corresponding temperatures, be drawn to the same scales, the condensation temperature curve can be connected with them by placing its origin at a point on the time scale determined by the following considerations. The rate of rise of mean temperature of the steam in the clearance after the admission of the auxiliary-boiler steam must depend upon the velocity of the latter through the steam pipe, and this is taken for calculation at 800 feet per second. During admission the steam in the clearance space must at the same instant vary in pressure and temperature from point to point; but the steam which is in contact with the walls must have the same temperature as the surface of the metal. A curve of rise in mean temperature of steam during admission, starting from the temperature t_c, and a corresponding curve of surface temperature according to equation (9), can therefore be drawn to determine the time at which the temperature of the surface of the metal reaches the highest calculated value of t_z, when the condensation of the steam from the auxiliary boiler begins. These curves are shown in the diagrams, Plates 31 to 39, by the full line Z O of calculated mean steam temperature during admission, and by the dotted line ZZZ of calculated surface temperature. The line OO is the calculated steam temperature during condensation; and the length included between these letters is the portion of the curve to which the tabulated values of s, y, z, and U refer. I I I are the curves from the indicator diagrams in Plates 22 to 30, B B the line of auxiliary-boiler temperature, and A A the main-boiler temperature. During the period of condensation nothing approaching the auxiliary-boiler pressure is recorded by the indicator, which shows only an apparently irregular curve.

An approximate calculation of the rate of initial condensation in the cylinder of a brass indicator shows that the fall of temperature of the steam must take place at a much quicker rate than in the engine cylinder; and it is probable that the changes of pressure take place so rapidly that, owing to inertia, the indicator piston has not time to follow them, and that therefore the momentary duration of the boiler pressure cannot be recorded by it. Further experiments however are required to determine this point; and all that can be said with certainty at present is that pressure must exist to fill the clearance, which is not shown on the indicator diagrams.

In trials 3 to 12 the jacket space in the cylinder cover was filled from the barrel-jacket, and drained back into it. In trials 14 and 22, it was filled from the barrel-jacket, and separately drained through a trap. In trials 15 to 18 and 23 to 26, the communications were plugged, so that no steam entered the cover-jacket. Trials 14 and 15 were witnessed by Mr. Bryan Donkin, who kindly verified the measurements relating to them.

Evaporation of Water by Surface Condensation of Steam.—Similar equations to the foregoing can be employed to represent the results of the process of evaporating water by the surface condensation of steam on a metallic plate. During steady ebullition it is probable that no film, either of water or of steam, can permanently adhere to the surface from which the evaporation is taking place; but that minute particles of water are periodically brought into actual contact with the metal, and thereby changed into steam. The momentary rate of flow of heat which results from this contact will be extremely rapid, as compared with the rate of transmission of heat by conduction through a measurable thickness of metal; and the change of any one of the particles of water into steam, whatever may be the nature of the process, will probably absorb the whole available heat from a small area of an exceedingly thin surface layer of metal. The steam produced will then act as a non-conducting medium, until an amount of heat equal to that abstracted by evaporation is returned to the surface layer by conduction through the metal. Ebullition may therefore be considered as an intermittent process, consisting of a

series of cycles, in any one of which the distribution of heat will, at the moment of evaporation of a particle of water, be the reverse of that at the first instant of the process of condensation, when the rate of flow of heat is so rapid as to make the transmission virtually instantaneous.

Let t_e be the temperature of evaporation ; t_y the temperature of the evaporating surface common to the water and the metal ; and t_z the temperature of the interior of the metal. Then for cast iron

$$\Delta\, U = 37\cdot 5 \times 0\cdot 13 \times (t_y - t_e) \times \Delta y$$

will be the heat instantaneously abstracted by evaporation from one square foot of the surface layer of which Δy is the thickness ; and

$$\Delta\, U = 37\cdot 5 \times 0\cdot 13 \times \frac{t_z - t_y}{2} \times \Delta y$$

will be the heat gradually restored by conduction to the same surface layer.

$$\text{Hence} \quad t_z - t_y = 2\,(t_y - t_e).$$

By a similar equation to (9) $t_y - t_e = \dfrac{2925}{w\,L}\,(t_z - t_y)^2$,

$$\text{and therefore } t_y - t_e = \frac{w\,L}{11700} \quad . \quad . \quad (11)$$

Comparison of Calculated with Observed results.—The results of experiments on the transmission of heat from a steam-jacket through cast-iron cylinder liners of varying thickness, which were communicated to the Institution by Mr. Morison at the meeting in October 1892, page 485, will enable a test of these conclusions to be made. In those experiments, during steady evaporation, the thickness of the film of condensed water remaining on the outer surface of the liner must evidently be constant, and would be limited by the formation of drops. This limiting thickness the author considers for rough vertical cast-iron surfaces will probably be near 0·005 inch, and assuming it to be 0·0051 inch, y being taken as the thickness of the liner, and t_b as the temperature of the jacket steam, the equations representing the steady flow F of heat will be

$$F = \frac{dU}{ds} = \frac{0\cdot 00125\,(t_b - t_z)}{0\cdot 0051} = \frac{0\cdot 125\,(t_b - t_y)}{y + 0\cdot 51}$$

In this case $t_e = 212°$, and from equation (11)

$$t_y = 212° + \frac{966\ w}{11700} = 217°\ ;$$

$$\text{hence } F = \frac{t_b - 217°}{8y + 4{\cdot}08} \quad * \qquad (12)$$

will give the number of thermal units passing through the liner per square foot per second. The weight of water evaporated per hour can be calculated from this equation, when the temperature to which the feed-water is raised by the escaping heat is known. This temperature is not given in Mr. Morison's communication; but assuming it to be 100°, then

$$\left.\begin{array}{l}\text{Lbs. of water evaporated}\\ \text{per hour at 212° Fahr.}\end{array}\right\} = \frac{3{,}600 \times \text{sq. feet internal surface} \times F}{966° + 212° - 100°} \quad . \ (13)$$

From this equation the calculated results are obtained which are given in Table 23 in juxtaposition with the corresponding actual results observed in Mr. Morison's experiments. In the diagram, Plate 40, are shown by dots the actual results obtained; and the inclined straight lines are drawn in accordance with calculation from equations (12) and (13). The diagram is also furnished with a scale of thickness of metal, by which the relation between the number of pounds evaporated and the temperature of the condensing steam can be seen for any thickness of liner up to one inch. The results shown in the table and diagram not only indicate the remarkable accuracy of Mr. Morison's experiments, but also confirm the values of the coefficients of conductivity for water and cast-iron, as well as

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* A direct experiment shows that at a temperature of 60° Fahr. the thickness of the film of water which will remain on a vertical plane surface of cast-iron rough from the sand is 0·0041 inch, and that this thickness is reduced to 0·0027 inch when the surface is roughly planed, and to 0·0023 inch when it is polished. If the cylindrical shape of the liner is taken into account by means of the formula $F = 0{\cdot}125\ (t_b - t_y) \div (R\ log_e \frac{R}{r} + 100\ z)$, where R and r are the outer and inner radii, the value 0·004 inch for z will give a near approximation to Mr. Morison's results. To determine from this formula the weight of water evaporated per hour, it would be necessary to know what proportion of the outer surface of the liner is effectively employed in the transmission of heat to the water; and recent experiments by Mr. B. Donkin and the author show that it is extremely difficult to ascertain this proportion accurately.

TABLE 23.—*Transmission of Heat from Steam-Jacket through Cast-Iron Cylinder-Liners of varying thickness.*

External Surface of Liner 11 inches diameter, 3·84 square feet.

Internal Surface of Liner:—

9·19 inches diameter, 3·007 square feet.
10·16 „ „ 3·324 „ „
10·62 „ „ 3·477 „ „

Pounds of Water Evaporated per hour at 212° Fahr. Plate 40.	Thickness of metal.	Steam Pressure in Jacket, pounds per square inch above atmosphere; and corresponding Temperature Fahr.							
		10 lbs. 240·1°	20 lbs. 259·3°	30 lbs. 274·4°	40 lbs. 287·1°	50 lbs. 298·0°	60 lbs. 307·5°	70 lbs. 316·1°	80 lbs. 324·1°
	Inch.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Observed Calculated	0·90	20½ **20·6**	37¾ **37·7**	51 **51·1**	62¼ **62·3**	72 **72·1**	80¼ **80·5**	88 **88·2**	95 **95·3**
Observed Calculated	0·42	35 **34·5**	63 **63·2**	84¾ **85·7**	102¼ **104·5**	119 **120·8**	133 **135·0**	145½ **147·9**	157 **159·8**
Observed Calculated	0·19	47½ **47·9**	87½ **87·7**	119 **119·0**	145¼ **145·3**	168 **167·9**	188 **187·6**	206 **205·5**	222 **222·1**
Calculated Temperature of exterior surface of metal, t_s	0·90 0·42 0·19	231·7° 227·4° 223·3°	244·0° 236·1° 228·5°	253·6° 242·9° 232·6°	261·7° 248·7° 236·0°	268·7° 253·6° 239·0°	274·8° 257·9° 241·6°	280·3° 261·8° 243·9°	285·3° 265·4° 246·1°

the view which the author has adopted, that there is no specific surface-resistance in cast-iron to the entrance or egress of heat.

Steam Condensation in Surface Condenser.—The weight of steam which can be condensed on a metallic surface, and the corresponding rise in temperature of circulating water, may also be similarly calculated. There is ample and trustworthy experimental evidence to show that a flow of heat through a tube or plate can readily be produced, which, although considerably less than when ebullition takes place, is far in excess of any that can be accounted for by conduction through water, or by convection. It is therefore probable that the heat is in the first instance absorbed by the evaporation of portions of a thin film of water, of which one surface momentarily adheres to the metal, whilst the other surface flows with the circulating water; and that the steam thus produced is immediately recondensed, giving up its heat to the surrounding water. Let c be the weight of circulating water, in pounds per second, passing over a square foot of the surface, and v its velocity in feet per second; then the mean velocity of the adherent film will be $\frac{v}{2}$; and let x be its thickness in inches. Let t_i be the initial and t_f the final temperature of the circulating water; and as before, let t_b be the temperature of the steam supply; t_z the temperature of the surface of the metal next the steam, and t_y the temperature of the surface next the circulating water; z the thickness of the film of condensed water remaining on the surface next the steam. Then if the metallic surface be that of a brass tube, through which the circulating water flows, of thickness y, and with a coefficient of conductivity $0 \cdot 25$, the equations representing the flow of heat F_i per square foot per second at the entrance of the circulating water into the tube will be

$$F_i = 0 \cdot 00125 \times \frac{t_b - t_z}{z} = 0 \cdot 250 \times \frac{t_z - t_y}{y}$$

$$= 0 \cdot 00125 \times \frac{t_y - t_i}{x} = \frac{62 \cdot 5}{12} \, x \, L \, \frac{v}{2};$$

from which $(t_b - t_y)^2 = 0 \cdot 0521 \, (200 \, z + y)^2 \, (t_y - t_i) \, Lv$,

and $F_i = 0 \cdot 0571 \, \sqrt{(t_y - t_i) \, Lv}$.

TABLE 24.—*Steam Condensation in Surface Condenser.*

Position of Tube, vertical or horizontal		Tube Vertical.			Tube Horizontal.		
Number of experiment		1	2	3	4	5	6
Weight c of circulating water per square foot per second	lb.	0·1830	0·6312	0·8845	0·1758	0·6958	0·9418
Velocity v of circulating water, feet per second	feet	1·35	4·63	6·50	1·30	5·12	6·92
Latent heat L of evaporation of circulating water per lb.	th. units	1026	1052	1056	1017	1045	1051
At Entrance.							
Difference of temperature between water and steam, $t_b - t_i$	Fahr.	197°	197°	198°	195·2°	195°	196°
Difference of temperatures in circulating water, $t_y - t_i$	Fahr.	75·5°	37°	29°	112°	66°	57°
Flow F_i of heat per square foot per second	th. units	18·5	24·3	25·5	22·0	33·9	36·8
At Exit.							
Flow F_f of heat per square foot per second	th. units	12·5	20·6	22·5	14·0	28·1	31·5
Rise of temperature of circulating water, $t_f - t_i$	Fahr.	79·5°	34·5°	26·5°	95·0°	43·0°	35·0°
Difference of temperatures in circulating water, $t_y - t_f$	Fahr.	35·0°	26·5°	23·0°	46·0°	45·5°	42·0°
Difference of temperatures in metal, $t_z - t_y$	Fahr.	2·5°	4·0°	4·5°	3·0°	5·5°	6·0°
Difference of temperatures in condensed steam, $t_b - t_z$	Fahr.	80·0°	132·0°	144·0°	51·0°	101·0°	113·0°
Final Temperature t_f of Circulating Water, Observed	Fahr.	140·0°	93·5°	85·0°	165·0°	101·0°	94·5°
Final Temperature t_f of Circulating Water, Calculated	Fahr.	**137·5°**	**92·5°**	**84·5°**	**153·0°**	**101·0°**	**93·0°**
Steam Condensed per square foot per hour, Observed	lbs.	52·32	78·18	84·34	67·8	104·6	121·3
Steam Condensed per square foot per hour, Calculated	lbs.	**53·4**	**78·4**	**84·2**	**62·5**	**109·5**	**120·3**

The rise of temperature of the circulating water, as it passes along the tube, will reduce the flow of heat, and the diminution of flow probably varies as the square root of the time; on this supposition, if F_f be the flow of heat per square foot per second at the exit of the circulating water from the tube,

$$t_f - t_i = \frac{F_i}{c} - \frac{2}{3}\,\frac{F_i - F_f}{c} = \frac{F_i + 2\,F_f}{3\,c}\text{ ; and}$$

$$F_f = t_b - t_i - \frac{F_i}{3c} - (t_y - t_f) \div (800\,z + 4y + \frac{2}{3c}) = 0{\cdot}0571\,\sqrt{(t_y - t_f)\,Lv}$$

from which the values of t_f and F_f can be determined.

The weight of steam condensed per square foot per hour will be

$$3{,}600 \times \frac{F_i + 2\,F_f}{3} \div \left(L + \frac{t_b - t_z}{2} \right).$$

Comparison of Calculated with Observed results.—A comparison of these calculations with actual results is shown in Table 24, for experiments on surface condensation made by Mr. B. G. Nichol, and given in "Engineering," 10 December 1875, pages 449–51. In these experiments with a brass tube $\frac{3}{4}$ inch diameter and $65\frac{1}{8}$ inches long, $y = 0{\cdot}049$ inch, $t_i = 58°$, $t_b = 255°$ approximately, and the values of c and v are known. It is necessary to assume the value of z, which is taken as $0{\cdot}008$ inch when the tube was vertical, and $0{\cdot}0045$ inch when horizontal. The latent heat of evaporation L is taken for the circulating water as corresponding with the temperature $t_i + \frac{F_f}{c}$, and for the condensed steam as corresponding with t_b.

MEMOIRS.

ARTHUR EDWIN BATTLE, born at Potter Hanworth, Lincoln, on 5th May 1857, was the youngest son of Alderman J. R. Battle, J.P., of Lincoln, and was educated at Edenfield, Doncaster. On leaving school he was apprenticed to Messrs. Ruston, Proctor and Co. Having passed through the various workshops, he travelled for the firm in South Africa, Australia, South America, India, Mauritius, Sumatra, Java, Japan, and elsewhere, returning to England in 1890. After remaining six months, he went out again to Australia, and entered into partnership with Mr. C. W. Gibson, of Sydney, trading as Gibson, Battle and Co., of Melbourne and Sydney, and acting as agents there for Messrs. Ruston, Proctor and Co. His death occurred suddenly at Melbourne from hemorrhage on the brain on 7th January 1894, at the age of thirty-six. He became a Member of this Institution in 1891.

FRANCIS LEAVER GUILFORD was born in Nottingham on 29th December 1842. After being educated at Bristol he was articled in 1859 to Messrs. Robert Stephenson and Co., engineers, Newcastle-on-Tyne. On completing his apprenticeship, in order to gain experience he undertook the superintendence of several important contracts for Messrs. Simpson and Co., Pimlico, London. Quitting their service in 1867 he joined his brother-in-law, Mr. G. R. Cowen, in the engineering business of Messrs. G. R. Cowen and Co., Beck Works, Nottingham, of which he was acting manager for over a quarter of a century. His death took place at Nottingham on 30th March 1894, at the age of fifty-one. He became a Member of this Institution in 1870.

JOHN HENRY HARRIS was born at Troy, in New York State, on 4th January 1838. His father removed to Springfield, Massachusetts, while he was a boy, and there his early education was acquired.

He served his time on board a clipper ship, and on the outbreak of the Civil War in 1861 he offered himself as a volunteer in the United States Navy. His first appointment was that of acting master's mate, followed by that of acting ensign in 1862, and acting master in 1864. He participated in the naval engagements at Newport News, Port Hudson, Fort Fisher, and elsewhere. After leaving the government service in 1866 he removed to Worcester, Massachusetts; and having decided to become a lawyer he entered the office of Senator George F. Hoar. The routine of a lawyer's office proving uncongenial, he made arrangements with Messrs. George F. Blake and Co., of Boston, who were manufacturers of steam pumps, to go to New York and take charge of that branch of their business, which he managed successfully for several years. After an attempt to carry on the manufacture of steam pumps at the Reading Hydraulic Works, in Reading, Pennsylvania, he became connected with the firm of Messrs. Henry R. Worthington, by whom he was sent to England, where he founded the Worthington Pumping Engine Co. in London. He remained with this firm for about twelve years up to the time of his death, which took place at New York, after a long illness on 22nd January 1894, at the age of fifty-six. He became a Member of this Institution in 1885, and was a member of several other scientific societies in Europe and America.

JOHN HICK was born at Bolton on 2nd July 1815. He was the eldest son of the late Mr. Benjamin Hick, one of the founders in 1833 of the engineering and millwright business constituting the Soho Iron Works. After being educated at the Bolton Grammar School he entered these works, where he soon took an active part in the management, for many years in partnership with his father, and on the death of the latter in 1842 with the late Mr. William Hargreaves. In 1868 he was elected Member of Parliament for Bolton, and immediately after his election he relinquished his connection with the Soho Works in consequence of government contracts being then in the hands of the firm. The frequency of explosions of steam boilers induced him to bring the subject before parliament; and in May 1870 upon his proposal a select

committee was appointed, of which he was chairman, to enquire into the cause of these disasters and the best means of their prevention. In their report certain recommendations were made with the view to securing greater safety for steam boilers; and one of the suggestions was in favour of periodical but not compulsory inspection. In August 1871, shortly after the presentation of the report, he introduced a bill to provide a more efficient remedy to persons injured and property damaged by the explosion of steam boilers through negligence. He also served on a select committee in 1874 to consider the best chain cables and anchors for the navy; and amongst other matters to which he drew the attention of parliament were the importance of the British army being provided with the most effective rifle, and the improvement of heavy ordnance. He retired from parliament in 1880. In his native town he held many public positions, and was also a justice of the peace and a deputy lieutenant of the county of Lancaster. He had been in failing health for some months previous to his death, which took place at his residence, Mytton Hall, near Whalley, Lancashire, on 2nd February 1894, at the age of seventy-eight. He was an original member of this Institution from its formation in 1847 till 1852; and having rejoined in 1871, he was elected a Member of Council in 1872, and a Vice-President from 1874 to 1876. He was also a member of the Institution of Civil Engineers. In 1849 he contributed a paper to this Institution on a frictional starting and disengaging apparatus for connecting and disconnecting the driving power with shafts and machinery.

ANDREW LESLIE was born in Shetland on 1st September 1818. He was brought up in Aberdeen, and there served his apprenticeship to Messrs. Bowman and Vernon, working first as a rivet catcher and afterwards as a boiler maker. Before he was out of his time he had given indications of that assiduity and keen grasp of work which afterwards became so marked; and he was speedily promoted to a good position. After remaining a few years longer with the firm he commenced business for himself at Aberdeen in 1850 as a shipbuilder; and in 1854 went to

the Tyne, where only three shipbuilding yards existed at that time. Having selected Hebburn as the place to start in, he commenced work there at once as an iron shipbuilder, and founded the firm of Andrew Leslie and Co. He quickly saw the advantage of having his workmen around him, and began the work of building Hebburn by erecting houses for them. The shipbuilding yard prospered rapidly, and soon took a place in the first rank from the high character of the work turned out, growing and expanding in every way till it came to give employment to about 3,000 hands. During the same time more than a thousand houses were erected for the workmen and other persons employed, together with an institute and school and a costly church. Having aspired to founding a town at Hebburn as well as a great shipbuilding yard, he had succeeded in doing so before he gave up his busy life. In 1885 he retired from the firm, after having built over 200 ships, including the twin steamer "Calais-Douvres" for channel service. A project which he had greatly at heart, but did not live to see commenced, was the construction of a ship canal from the Tyne to the Solway; and another was the erection of a railway bridge over the Tyne from Hebburn to Wallsend. He was a magistrate at Hebburn, and for the counties of Durham and Northumberland, and was also a member of the Tyne Commission. Having been suffering for some time from weakness of the heart, he had apparently recovered sufficiently to be on the point of starting for the south, when his death took place suddenly at his residence, Coxlodge Hall, near Newcastle, on 27th January 1894, at the age of seventy-five. He became a Member of this Institution in 1858.

Joseph Tomlinson was born in London on 11th November 1823, and was educated from 1831 to 1836 at a private school in London, and in Darlington 1836–37. From 1837 to 1839, his father being at that time passenger superintendent of the line, he had the run of the shops of the Stockton and Darlington Railway at Shildon, of which Mr. Timothy Hackworth was then the locomotive superintendent. From 1839 to 1842 he was in the shops of the Manchester and Leeds Railway at Miles Platting, Manchester. In July 1846 he joined the

London and South Western Railway as outdoor foreman at Nine Elms, under Mr. John V. Gooch, and had charge of the engines and working of the whole of the London district until 30th June 1852, the last two years with the late Joseph Beattie. At the time of the Great Exhibition in 1851 he frequently drove the special train taking Prince Albert from Windsor to Waterloo and back, accompanied sometimes by his two sons, the Prince of Wales and Prince Alfred. In 1852 he joined the London and North Western Railway at Crewe as draughtsman in charge of the locomotive engine works, under the late Francis Trevithick and the late Alexander Allan. In 1853, on Mr. Allan joining the Scottish Central Railway, he was appointed his assistant. In September 1854 he was appointed assistant to the late Matthew Kirtley at Derby, in charge of the outdoor working of the locomotive department of the Midland Railway system. During his service here the transition took place from the use of coke to that of coal as fuel for locomotive engines, and the alterations necessary for success had to be devised; a series of experiments carried on over a considerable period resulted in the adoption of the deflector plate in the fire-door hole, and the brick arch in the fire-box, both of which continue to the present day to be the best known means for preventing smoke and the escape of sparks, and for ensuring as far as possible the perfect combustion of the fuel. He also carried out the important work of classifying the engines more completely for their different duties and districts. The locomotives being also in a bad state, owing to sufficient numbers not having been added for the increasing traffic, had to be brought up fairly to the requirements of the time; and this had only just been accomplished, when in January 1858 he was appointed locomotive superintendent of the Taff Vale Railway at Cardiff. Here he found himself at the very outset driven to the use of coal alone for carrying on the traffic, in consequence of the continued strike of the colliers in the Rhondda Valley, where the coking coal was obtained; and he therefore tried the experiment of covering up the entire surface of the fire-bars with small pieces of broken fire-brick, not exceeding three inches cube, and putting the fire upon them, so as to prevent the direct action of the fire on the

iron of the bars, by which previously they had been so rapidly burnt out as to render the use of the Welsh steam coal impracticable in locomotives. Of this simple plan, which at once proved successful, he gave a description with results in a paper to this Institution in the same year (Proceedings 1858 page 274). He also improved upon the existing design of locomotive with six wheels all coupled, by adding compensating levers between the leading and driving wheels, and by other modifications in detail. In 1863 he represented the South Wales Steam Collieries Association in the experiments at Devonport, extending over many weeks; and reported unfavourably on the mixture of North-country coal and Welsh dry coal, which up to that time had been used by the government. The experiments were published in a blue book, and resulted in the use of the mixture being discontinued. In 1869 he resigned his position on the Taff Vale Railway, owing to some political difficulty; and started on his own account in Cardiff as a consulting engineer in shipping and in marine and land engines. In 1872 he was invited to join the Metropolitan Railway as resident engineer and locomotive superintendent, in which double capacity he gradually worked up the line into a condition of prosperity. When the original Chapel Street Works at Edgware Road Station became altogether inadequate to the increased requirements of the locomotive department, he designed and laid out the new locomotive and carriage works at Neasden. Before removing from the Chapel Street Works he carried out there a series of experiments for this Institution on the friction of journals; and in 1885 was appointed Chairman of the Research Committee of the Institution on the subject of friction. In April 1885 he resigned his position on the Metropolitan Railway, and resumed practice as a consulting engineer. In this capacity he was called in to design and superintend the erection of new supports for carrying the overhead telephone wires in London, which had collapsed in the severe snowstorm in the winter of 1887; and was also consulted in regard to the surveying for new lines of wire to provincial towns, and other matters connected with the telephone system. In 1890, in conjunction with Mr. Samuel Swarbrick, formerly general manager of the Great Eastern Railway, he was appointed to investigate the

management and working of the Taff Vale Railway; and the elaborate report which they jointly prepared having resulted in various improvements, he was elected on the new board of directors in 1891. The labour and exposure attending the work of investigation, which was carried on during the winter of 1890–91, doubtless told upon his health and strength, though the ultimate effects did not become apparent till the spring of 1893. From this time he was more or less confined to his house, and though frequently rallying, and throughout retaining his whole interest in all engineering work that was going on, he never recovered sufficiently to get about again, and died at his residence at West Hampstead on 22nd April 1894, at the age of seventy. In 1871 he was elected an Associate, and in 1874 a Member, of the Institution of Civil Engineers. Having been a Member of this Institution from 1857, and for many years a Member of Council and a Vice-President, he was elected President in 1890 and 1891. His presidential address in 1890 (Proceedings page 181) contained his own personal recollections of the development which he had witnessed of the locomotive engine from the year 1837; and in his own words therein recorded "I soon fell in love with a *live engine*, and from then to now have had a feeling of first love for it."

William Walker was born at Houghton-le-Spring, Durham, on 14th November 1830. He served his apprenticeship of seven years at the engine works of the Thornley Colliery; and afterwards worked at the locomotive works of the North Eastern Railway, Bank Top, Darlington, and for a year at the works of Messrs. Fossick and Hackworth, Stockton-on-Tees. In 1853 he went to Messrs. Thomas Richardson and Son, Hartlepool, and was with them for three years, during two of which he was one of their leading hands, and went to sea as engineer in charge of the first, second, and third steamers built by them. In 1856 while with their third steamer he accepted an engagement with the Borneo Co. Afterwards he was appointed superintendent engineer to the Netherlands India (Java) Mail Co., with whom he remained ten years until the expiration of their mail contract in 1869, continuing afterwards with their successors till

1873 as sole manager of their works at Sourabaya, Java. While in Java he designed and erected for the Dutch government an iron light-house in the Madura Straits. Since 1873 he imported on his own account sugar-making and other machinery into Java and other sugar-growing countries; and also designed and superintended the arrangement and construction of many of the most important sugar factories now existing in Java and elsewhere. He was one of the pioneers of economical working in the manufacture of sugar, by the improvement of cane-crushing mills with the object of extracting every possible drop of juice from the sugar cane, and by the utilization of exhaust steam for evaporative purposes in modern appliances, such as the triple and quadruple "effet," as opposed to the open-pan method of evaporation, and by the introduction wherever possible of labour-saving machinery in the manipulation of the sugar-cane products. He was also largely interested in machinery for treating coffee, in which he introduced many improvements, and also for ice-making. In 1878 he received a gold medal from the third Indian Agricultural Congress in appreciation of his services. His death, which resulted from injuries received through a fall from his horse on 9th April 1894, took place at his residence at West Dulwich, London, on 29th April, at the age of sixty-three. He became a Member of this Institution in 1878; and was also a member from 1866 of the Nederlands Koninklijk Instituut van Ingenieurs.

Joseph Wright was born at Dudley on 7th October 1826. He served his time partly at his father's works in Dudley and partly at Messrs. Cochrane's iron works at Woodside. On the expiration of his apprenticeship he remained at Messrs. Cochrane's as an erector, and was entrusted with the execution of some important undertakings, including the erection of large works in connection with the first railway in India. After his return from India he superintended the erection of the Ormesby Iron Works, Middlesbrough. On the completion of the works he became a partner in the firm of Messrs. Head, Wrightson and Co., Stockton-on-Tees, then trading as Head and Wright, and was largely instrumental in the foundation of

this business. In this connection he designed several important appliances and improvements relating to foundry and blast-furnace plant, including a method of making railway chairs cheaply; he also designed and built several large blast-furnaces, introducing many improvements in this industry. On the dissolution of the partnership in 1862 he returned to Dudley, and founded a business with his father-in-law, Mr. Thomas Tinsley, as chain and anchor makers at Tipton, which rapidly extended, until under the title of Joseph Wright and Co. it became one of the largest chain and anchor works in England. At these works he made Martin's self-canting anchor, now universally used. About this time he carried out some extensive alterations at the Old Park Furnaces in Shropshire; and shortly afterwards took up the Berryman feed-water heater, which he greatly improved in many points. In 1887 he retired from the firm, and practised as a consulting engineer in Westminster, at the same time carrying on the manufacture of heaters, evaporators, condensers, water softeners, and other appliances connected with the purification of water. His last invention, completed only a few days before his death, was a high-speed engine for electric-light purposes. During the last eight years he suffered from cancer in the throat, from which he died on 20th October 1893, at the age of sixty-seven. He became a Member of this Institution in 1860.

Institution of Mechanical Engineers.

PROCEEDINGS.

April 1894.

The Spring Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Thursday, 19th April 1894, at Half-past Seven o'clock p.m.; Professor Alexander B. W. Kennedy, LL.D., F.R.S., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following thirty-five candidates were found to be duly elected:—

MEMBERS.

Accles, William Sloane,	Birmingham.
Bentley, George,	Bury.
Davis, George,	Manchester.
Gregory, Horace Mark,	London.
Hamilton, Robert,	Penang.
Harding, James Cooper,	Erith.
Jackson, John Broad,	Bury.
Mansfield, Edwin,	Manchester.
Poland, William,	London.
Saxon, James,	Manchester.
Walker, Henry Claude,	London.
Whitby, Arthur George,	Amersham.

ASSOCIATE MEMBERS.

Almond, Michael, . . .	Queenstown, S. Africa.
Ambler, Frank, ...	Maceio, Brazil.
Baron, Francis Edward, . .	Kingston-on-Thames.
Dunolly, Alan, ...	Bolton.
Hadengue, Charles Benjamin, .	Rosa, India.
Murphy, Edward Owen, . .	Vancouver.
Poppleton, Clement Francis, .	London.
Rowe, Daniel, ...	Redruth.
Taylor, William, . . .	Leicester.

ASSOCIATE.

Hayes, John, ...	Birmingham.

GRADUATES.

Ambrose, Sewell Powis, . .	Thetford.
Aylesbury, Thomas Antram, . .	Sutton, Surrey.
Cater, John McIlvaine, . .	Thames Ditton.
Darwood, John William, . .	London.
Fry, Henry Walter, . . .	Brighton.
Hodges, Frank William, . .	London.
Ironside, William Allan, . .	London.
Larmuth, William Oliver, . .	Manchester.
Mansfield, Walter, . . .	Manchester.
Moon, Edgar Rupert, . . .	Swindon.
Richmond, William Frederick, .	Dublin.
Skinner, Russell Foster, . .	London.
Thorpe, Wilfred Bertram, . .	London.

The President then delivered his Inaugural Address: after which the following Paper was read and partly discussed:—

"Description of the Grafton High-Speed Steam-Engine;" by Mr. Edward W. Anderson, of Erith.

At a Quarter to Ten o'clock the Meeting was adjourned to the following evening. The attendance was 100 Members and 116 Visitors.

The Adjourned Meeting was held at the Institution of Civil Engineers, London, on Friday, 20th April 1894, at Half-past Seven o'clock p.m.; Professor Alexander B. W. Kennedy, LL.D., F.R.S., President, in the chair.

The Discussion upon Mr. Anderson's Paper on the Grafton High-Speed Steam-Engine was resumed and concluded; and the following Paper was read and discussed:—

"Description of a Fluid-Pressure Reversing Gear for Locomotive Engines;" by Mr. David Joy, of London.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated at Ten o'clock. The attendance was 65 Members and 52 Visitors.

The Anniversary Dinner of the Institution was held at The Freemasons' Tavern, Great Queen Street, Lincoln's Inn Fields, on Wednesday evening, 18th April 1894, and was largely attended by the Members and their friends. The President occupied the chair: and the Guests of the evening were the Right Honourable

Lord Kelvin, President of the Royal Society; the Honourable Mr. Justice Romer; Dr. J. Russell Reynolds, F.R.S., President of the Royal College of Physicians; and Sir Richard E. Webster, G.C.M.G., Q.C., M.P. The following Guests also accepted the invitations sent to them, though those marked with an asterisk * were unavoidably prevented at the last from being present. The Right Honourable Lord Rayleigh, F.R.S., Honorary Life Member; The Right Honourable Lord Reay, G.C.S.I., G.C.I.E., Vice-President of University College, London; Sir Frederick A. Abel, Bart., K.C.B., D.C.L., D.Sc., F.R.S., Honorary Life Member; Sir Henry G. Bergne, K.C.M.G.; Sir T. Salter Pyne, C.S.I.; Sir Samuel Black, Town Clerk of Belfast.

Mr. Alfred Giles, President of the Institution of Civil Engineers; Mr. J. F. Rotton, Vice-President of the Senate of University College, London; Mr. E. Windsor Richards, President of the Iron and Steel Institute; Mr. Thomas Daniels,* President of the Manchester Association of Engineers; Mr. Robert Thompson,* President of the North-East Coast Institution of Engineers and Shipbuilders; Dr. John Hopkinson, F.R.S., President of the Northern Society of Electrical Engineers; Mr. Henry Edmunds, Vice-President of the Northern Society of Electrical Engineers; Dr. William Pole,* F.R.SS.L. & E., Honorary Secretary of the Institution of Civil Engineers.

The Rev. Canon Ainger, LL.D.; The Rev. Canon Bonney, F.R.S., University College, London; Professor David S. Capper, King's College, London; Mr. W. Hayes Fisher, M.P.; Professor G. Carey Foster, F.R.S., Dean of the Faculties of Arts and Laws, University College, London; Professor D. E. Hughes, F.R.S.; The Rev. Dr. John Kennedy; Councillor A. D. Mackenzie, Edinburgh; Professor W. C. Roberts-Austen, C.B., F.R.S., Chemist to the Royal Mint; Captain H. Riall Sankey; The Rev. Frederick J. Smith, Millard Lecturer, Trinity College, Oxford; The Rev. Dr. Wace, Principal of King's College, London; Mr. R. W. Wallace; Mr. Charles J. Wilson, F.I.C.

Mr. Edward W. Anderson; Mr. David Joy; Mr. Harry Lee Millar,* Treasurer.

The President was supported by the following Officers of the Institution:—*Past-Presidents*, Dr. William Anderson, F.R.S., Sir Edward H. Carbutt, Bart., and Mr. Jeremiah Head. *Vice-Presidents*, Sir Douglas Galton, K.C.B., D.C.L., F.R.S., and Mr. E. Windsor Richards. *Members of Council*, Mr. John A. F. Aspinall, Mr. William Dean, Mr. Benjamin A. Dobson, Dr. John Hopkinson, F.R.S., Mr. Arthur Keen, Mr. William Laird, Mr. T. Hurry Riches, Dr. William H. White, C.B., F.R.S., and Mr. J. Hartley Wicksteed.

After the usual loyal toasts, the President proposed "The Scientific and Professional Societies," which was acknowledged by the Right Honourable Lord Kelvin, LL.D., President of the Royal Society, and by Dr. J. Russell Reynolds, F.R.S., President of the Royal College of Physicians. Sir Douglas Galton, K.C.B., D.C.L., F.R.S., Vice-President, proposed the toast of "The Bench and the Bar," which was acknowledged by the Honourable Mr. Justice Romer and by Sir Richard E. Webster, G.C.M.G., Q.C., M.P. The toast of "Our Guests," proposed by Mr. J. Hartley Wicksteed, Member of Council, was acknowledged by the Rev. Canon Ainger, LL.D., and by Sir T. Salter Pyne, C.S.I., Engineer to H.H. the Ameer of Afghanistan. The concluding toast of "The Institution of Mechanical Engineers" was proposed by the Right Honourable Lord Reay, G.C.S.I., G.C.I.E., Vice-President of University College, London, and was acknowledged by the President.

ADDRESS BY THE PRESIDENT,

Professor ALEXANDER B. W. KENNEDY, LL.D., F.R.S.

It is a well-known difference between engineering practice in this country and in most others that the conditions of our work seldom allow us to carry specialisation to any such great extent as is common, for instance, all over the Continent. With us the belief that a man is "a thorough practical engineer"—whatever that may mean—is very generally taken as evidence that it is safe to ask him to do anything whatever which may be included within the vague general term "engineering." Of the extent to which this feeling is carried, as well as—I must say—of the essential truth which lies at the bottom of it, no better illustration could possibly be found than the position now held, with so much advantage to the public service, by my distinguished predecessor in this chair, Dr. Anderson. Some of us have occasion to examine continually the epitomised professional histories of engineers who wish to belong to, or to be promoted in, our Institutions. It is noteworthy in how many cases, especially in our own Institution, a man of thirty-five or forty is found to be working with great success in a line totally different from that in which he gained his first experience.

The existence in the minds of the public, who are in fact our employers, of the feeling which I have mentioned, no doubt brings us often into temptation,—temptation to undertake work or responsibility in directions where our own common-sense only, unaided by past experience, must be our guide. He is a wise man who can tell, as each opportunity presents itself, whether it is really a tide to be taken at its flood; or whether it is one in which his swimming powers will not be sufficient to carry him on to fortune, but may only leave him, and those who trust to him, still short of *terra firma*

when the ebb commences. The consideration of this point has probably caused many of us more anxious moments than the actual working out of any of the knotty engineering problems which come upon us after the plunge is taken. I speak in the matter from hard enough experience, for I myself have had all too often to decide such questions, sometimes in one sense and sometimes in the other. So it happens that having served my time with Marine Engineers, I have had in the last twenty-five years to busy myself with half a dozen varieties of mechanical and structural work, including what I may call the academic variety during many happy years at University College, and of late years also with the newest variety of all—Electrical Engineering. I trust that my electrical friends—those of them, that is, who are twenty years younger than I am—will forgive me for calling Electrical Engineering a variety of mechanical work. I mean nothing disrespectful of course; but even by those who are much more thoroughly electrical engineers than I can ever hope to be, but who have had the chronological misfortune, like myself, to have become engineers before technical electricity existed (if I may be allowed so to speak), I think electrical engineering must always be so regarded. To such of us, electrical work has been grafted on to mechanical; and any success we have had in the one, we trace back to its foundation in our knowledge of the other. And further—although I know that in this I lay myself easily open to an accusation of mere conservatism —I believe that even now the only really safe road to success in electrical work lies through the old routine of mechanical training, modified of course by the excellent means for studying the scientific side of the work which now exist in so many directions.

It is common, on occasions like the present, for the speaker to lay before the members such matters out of his own personal knowledge or research or experience as he thinks may be most generally useful to them, as some small acknowledgment of the honour which he has received at their hands in his election as their President for the year. In thinking how best I could fulfil this honourable obligation and pleasant duty, it occurred to me, in connection with the train of thought which I have just put before

you, that, as I happen by some chance to be the first of your Presidents who has been actively connected with electrical work, it might be of interest to you, and possibly also of use to some, if I endeavoured to put before you as clearly as I could the way in which the electrical problem of today in this country presents itself, when looked at from the mechanical engineer's point of view rather than from the electrician's—in other words, from your point of view and mine.

Practical electrical problems divide themselves probably into three main sections, in which electrical energy is used respectively for :—

i. Physico-Chemical processes.
ii. Power.
iii. Lighting.

Physico-Chemical use of Electricity.—The first section—where energy is used for the deposition of metals, for the reduction of chemical compounds, etc. — falls outside my own knowledge. From what I know of the success with which it is being worked, I cannot doubt that it has a great future. But its problems only touch engineering indirectly as yet, and therefore hardly come within the subject which I have prescribed to myself. In this section may be included, at least for present purposes, the application of electricity to heating. So many active and competent workers are at present engaged on this matter that it is greatly to be hoped that success may soon attend their work. Not only the difficulty of producing the heat, but also that of producing it in a convenient fashion, have been overcome to a very large extent. The remaining difficulty is the purely commercial one of producing the heat cheaply enough to allow of its general use. This, I am afraid, has not yet been overcome; and until it has been, electrical heating unfortunately comes hardly within our ken except for certain special purposes.

Remembering that something like 95 per cent. of all the energy that goes to incandescent lamps has hitherto appeared only as heat and not as light, there appears to be an ample opening here for

another "thermal storage" process, at least until the present lamps are superseded by the less wasteful type which the future will doubtless reveal to us in good time, and towards which we have already made sensible progress.

Power from Electricity.—The use of electrical energy for power, *i.e.* for transformation into mechanical energy, is a matter which lies obviously in the closest possible connection with mechanical engineering. It subdivides itself broadly into three sections, namely (1) Transmission from a distance for whatever purpose; (2) Transmission to a number of isolated points comparatively near together, as the tools in a factory; and (3) Transmission for the purposes of traction on railways or tramways.

The *transmission* comes in in every case, because we have as yet no electric prime-mover analogous to a steam engine. The electric motor pre-supposes the existence of a dynamo, which must itself be driven by some prime-mover. From the dynamo to the motor, whether near or far apart, there must always be transmission of electrical energy. In a recent extraordinary aberration it seems to have been discovered that there was some positive advantage in using steam engine, dynamo and motor all in one place to do work hitherto done by the steam engine alone. This wonderful locomotive however forms, and no doubt will continue to form, a class by itself!

Transmission from a distance. — As to the transmission of power from a distance I shall not say anything, mainly because I could say nothing so well as it has lately been said by Professor Unwin in his Howard Lectures to the Society of Arts. The whole matter is there discussed with so unusual a combination of impartiality, scientific accuracy, and mechanical common-sense, as to render the lectures, short as they are, one of the most important contributions to engineering literature which have appeared in this country for a long time. In particular, one cannot help being struck with the judicial way in which the author has kept clear of the fatal fascination which this

matter exercises over many minds otherwise sane—a fascination which in some cases goes so far that one finds the whole matter discussed, perhaps unconsciously, on the basis that it is a positive advantage to transmit power from the longest possible distance! There are several towns in the United Kingdom where the use of water power for the purpose of electric lighting will have some day to be seriously considered; but I hardly think that beyond these the present generation is likely to see any great development in this direction at home. In other parts of the world the conditions are of course different, and English engineers who wish to secure their share of work in this direction will rather have to study it beyond the limits of their own country.

Driving Tools by Electric Motors.—The question of driving the tools in a factory by electric motors, instead of through belts and shafting, is one which has recently come to the front. Obviously the carrying out of such work is purely a matter of mechanical engineering. Its advisability in any particular instance is partly a question of economy and partly one of convenience, and is undoubtedly dependent on the conditions of each individual case. I have found from information kindly given me by several large engineering firms, that the actual cost to them of power—including coal, stores, wages, and depreciation—generally lies between 2 and 5 per cent. of their total costs.

In any given factory running on the ordinary system there is a large continuous waste of power, due to the running of the whole shafting, no matter how many or how few machines are at work. Under such conditions the waste work in shafts and belts may well be 25 per cent. of the average useful work, and the distribution of total work may be approximately:—

	H.P.
Average useful work	100
Wasted in belts and shafting	25
Wasted in engine friction, at about 10 per cent. of maximum H.P., the engine being supposed large enough to give 150 H.P. at tools as a maximum .	20
	145

Now if all the machines in such a case were driven by separate motors, each having an electrical efficiency of 88 per cent., and these motors were worked from a dynamo having an efficiency of 92 per cent. (both of which are high figures for ordinary work at two-thirds output), the figures would stand as follows:—

	H.P.
Average useful work	100
Wasted in motors and dynamo	24
Wasted in leads (say 2 per cent.)	2
Wasted in engine friction (as above)	20
	146

It will be seen that the two sets of figures are practically the same as to amount of power required. As the electrical efficiencies which I have assumed are not likely to be exceeded, I think it may be said that there is no saving to be obtained in horse-power, and none therefore in any of the items of cost directly dependent on horse-power, in cases where the power wasted in shafting and belts does not exceed 25 per cent. of the whole average useful power. This is a ratio which any engineer can most readily obtain for himself, if he is not afflicted with that sense of the insuperable difficulty of making any simple and exact experiment which still remains one of the obscure diseases of our profession. I have no doubt cases can be found where the waste in large factories with widely distributed power is very much greater than the proportion assumed; and in such cases no doubt a saving in power costs would occur, in addition to the other advantages which I shall have to mention later on.

But at the root of the matter there probably lies one ultimate determining point, far too often neglected in such calculations as I have just been making. This point is, of course, the real absolute saving to be made, as distinguished from the proportionate saving. It is of little use to show an engineer that he can make even 20 per cent. saving in some one item of expenditure, if that whole item represents only 3 or 4 per cent. of his costs, and if at the same time he has to expend a considerable amount of capital in making the change. A manufacturer does not make important and expensive changes, especially changes whose result is by no means

certainly to be predicted, in order to bring about an *estimated* saving of half of 1 per cent. in his total expenditure. I fear that this is a matter which may prove a more serious difficulty in the way of the success of the great Niagara scheme than any of those described by Professor Forbes. In reference to our present point, it will prove sufficient to prevent the adoption of isolated motors in engineers' works in all cases except where the waste in belt and shaft transmission is unusually great, or where for other reasons electrical driving is in itself desirable.

For the whole matter is certainly not concluded, either one way or the other, by the single consideration of cost of power. There can be no doubt, on the one hand, of the practical convenience of getting rid of the huge mass of shafting, gearing, and belting, which fills up the upper half of many engineers' shops, although it is difficult to fix any money value for this advantage. There is no doubt also that a properly arranged motor may give a much larger range of speed to each tool than can be readily obtained in the ordinary way, and may thus enable more and better work to be got out of it, with skilful management. Were it not that such magnificent work has often been turned out in this country from such dirty and apparently disorderly shops, I should also say that it was self-evident that every change which improved the general orderliness and tidiness of the shop must—reacting upon the men employed—improve the output both in quantity and quality. Under the actual circumstances one hesitates to be dogmatic on this point; but I incline to believe that it is true, and that the good work to which I have referred has been turned out in spite of its environment, and has been due to exceptional excellence in workmen or managers or both, and that with the same men it might even have been still better under better working conditions.

On the other hand, it has to be pointed out that the cost of dynamo, leads and motors, is greatly in excess of the cost of shafting in almost every case. It is also hardly certain as yet how the costs of attendance, lubrication, renewals and repairs to the electrical plant, compare with the similar costs in the case of shafts and belting. Probably on the whole they would be less; but no satisfactory data on this point exist.

There arise two special cases which should be mentioned. Where electrical energy can be obtained from public mains, the comparison is quite different. The working of the printing machines, for instance, in the office of the *Pall Mall Gazette*, is carried out electrically, the current being derived from the mains of the Charing Cross and Strand Electric Supply Co. The works in this case get rid of all costs of engines and boilers, with all their many inconveniences, and also gain in space most of the room occupied by their old plant. Moreover they have a better security against breakdown than they could otherwise well afford to have without costly duplication of plant. The matter then becomes simply one in which increased space, convenience, and security, are to be balanced against increased cost; and each case has to be considered on its own merits. At present it is not very certain how the engineer supplying the electric energy ought to look at such a case. His chief business is, and probably always will be, to supply energy for lighting purposes. As is sufficiently well known, the demand for lighting energy varies enormously throughout the twenty-four hours: so that in fact a plant which is giving 2,500 H.P. for a couple of hours every day, and which of course must be large enough for this purpose, leaving still machines in reserve, will be giving only an average of 350 H.P. taken over the whole week, and not even half this for many hours every day and night. It is of course highly desirable to increase the load during the hours of light load; and if this could only be done without also increasing its present maximum, that is, without necessitating increase of plant, engineers could afford to sell the additional energy at a very low rate indeed. Unfortunately the condition I have mentioned is impossible. There will always come hours when, through fog or other special causes, the power load will coincide in time with the lighting load. And even if this were to happen only once or twice a year, the engineer must none the less provide plant for it and keep the plant ready. The case is not met by differential charges at different hours. The plant must be provided all the same, and the additional outlay will not be met by the extra payment for a few hours' work per annum. It may however be met very well by the value of the additional work done

on 360 days out of 365 at times when otherwise nothing would be done.

A second special case occurs when the cost of power forms a large instead of a small proportion of the whole running costs of the works; and no doubt in several industries this happens to a much greater extent than in engineering works.

I will ask you particularly to notice that, where electrical driving supersedes belts, the work is not done any less directly than before. Between the engine and the tool there stand, in the one case belts and pulleys and shafts, twice or thrice repeated; and in the other case dynamo and leads and motor, with or without a small belt from motor or machine. It is quite possible that the actual mechanical efficiency of the belts is greater than that of the two electrical machines and the leads between them. But with the shafts and belts the losses are continually going on, whether or not useful work is being done; whereas there are no losses in the motors unless they are actually running and driving tools. This brings the total losses equal in the case I have supposed, where the waste work was 25 per cent. of the total; and in other cases may make the electrical method more economical. But the change is merely a substitution of one indirect method for another equally indirect method.

Electric Traction.—In the third great subdivision of electric power transmission—for the purpose namely of driving trains or tramcars—we have a state of affairs which is entirely different, and which, I am afraid, is by no means so favourable to the use of electricity as is sometimes supposed. In a train drawn by an engine in the usual way, we have the whole of the net power of the engine—exclusive of that spent in internal friction and in actually hauling itself along—say 70 per cent.* of the gross indicated H.P., available

* In the address as delivered this percentage was stated, and probably overstated, at 80 per cent. But since it was delivered, Mr. F. W. Webb has kindly given me particulars of recent dynamometer and indicator trials which he has made on the London and North Western Railway, in which the draw-bar efficiency works out to a mean of 72·5 per cent. with two engines, each having coupled axles.

for pulling its load along the line. On an electric railway we have truly a somewhat lighter locomotive to be moved; but against this advantage and the fact that a stationary engine can have a greater economy than a locomotive, we have the uncomfortable condition that only some 35 per cent. of the whole I.H.P., as against 70 per cent., is available for the useful work of pulling the train. Moreover it seems hardly likely that this low percentage will be much increased. The cause of the loss is of course the extreme indirectness of the process, that is, the great number of transformations through which the energy has to pass, in each of which there is always a loss. We may take figures which correspond with American tram work approximately somewhat thus, always remembering that the average power would be less, probably much less, than three-quarters of the full power of the plant at work:—

	Per cent.
Mechanical efficiency of engine	85
Efficiency of belt-driving (if employed)	94
Efficiency of dynamo	90
Efficiency of line	85
Efficiency of motors	85
Efficiency of gearing on locomotives	75
Total efficiency	39 per cent.

From this is to be deducted say 10 per cent. for driving the locomotive, leaving only 35 per cent. for pulling the train. Where there is no gearing, as on the South London Railway and elsewhere in this country, the net efficiency would be raised to about 47 per cent., if the other quantities remained as above.

I think it may fairly be said that, to a mechanical engineer, the greatest enemy to all economy is frequency of transformation; and that it is, or ought to be, a fundamental rule in all engineering work that every unnecessary transformation, whether mechanical or electrical, should be avoided.

Notwithstanding this terrible drawback, the absence of foul gases is of such overwhelmingly great importance in some cases that the working of the City and South London Line has only been possible at all because electricity has been employed instead of steam. This of

course is a case where mere economy of power was not the only or even the most essential thing sought for. In the Liverpool Overhead Railway also the conditions of the case rendered the use of steam locomotives impossible, as the line runs along a route on which they are prohibited.

The case of tram lines along streets differs altogether from that of an underground or indeed any other railway. Here the steam engine with its boiler is a bulky and objectionable affair, apt to cause smoke and other disagreeables, and unsuitable for trains which consist of one vehicle only, weighing less than its locomotive would have to weigh. I have often wondered why the Serpollet boiler and engine have not been introduced for tram work. They take so little space that they might very possibly be put on the car itself, the car being made reversible as at Manchester; but I suppose some difficulties have been found; at any rate the proposal has not been made, so far as I know. But apart from this, and not forgetting the steam cars which are actually at work in certain places in the North, there is probably no form of steam car which would be generally endured by the public. Here again therefore electricity would appear to come in regardless of cost, in the same way as with the underground railway, although for another reason. But here we are met at once with the mechanical difficulty, not existing of course in the tunnel or on the overhead railway, of getting the current to the motors on the car. In America the knot is cut, rather than untied, by the use of overhead wires; and in country places it is probable that this may be here the best solution of the problem. But in our cities, where the bulk of the tramway traffic of the country is really carried on, I am still conservative enough to think and also to hope that this is impossible. Without forgetting the much-quoted case of Buda-Pest therefore, I fear that the introduction of electricity for car-driving in this country will still wait until a practicable underground system of conductors has been devised. Meanwhile it is being hard pressed by its rivals—cable and compressed gas. Of the two I think the latter, although the younger, is far the more formidable. It has the advantage of being even more direct than a steam engine, the boiler being absent; it can be applied to each individual car even more easily than an

electrical motor; and it enables the car to run freely on ordinary lines without their reconstruction, and without any mains either above or below ground. It has as yet had but short trial, but what I have seen of it makes me sanguine as to its ultimate possibilities.

Before speaking more particularly about the mechanical aspect of electric-lighting problems, I feel bound to touch upon a matter which arises directly out of the question of supplying electric energy for power and for light concurrently, to which I have already drawn attention. It is a favourite bit of cheap criticism, indulged in by those who have not to supply energy on a large scale, at the expense of those who have, that the latter class of folk show their ignorance of their own work and interests by neglecting to obtain that enormous demand for motive power which would come on them if only they reduced their prices low enough. The criticism is really as absurd as that other which censures the gas companies because they do not supply heating gas at a few pence per thousand feet: which apparently they would be perfectly able to do, if only they knew their own business half as well as their critics do! In both cases the criticism is mere words, "signifying nothing." We have simply to remember the fact that the mere possibility of driving something by electricity does not of itself create the things that want to be driven. There are isolated districts in London—Clerkenwell, for instance, and the neighbourhood of Fleet Street—in which there is a considerable amount of power of a kind which might be furnished electrically if the cost were made sufficiently low. In most parts however the whole energy expended in doing mechanical work is but a very small percentage indeed of the energy required for light; and it would not be increased in the least, even if the energy were supplied for nothing. When the inhabitants of Mayfair and Kensington, for instance—to take these districts only as typical of many others—take to brushing their boots, washing their faces, and serving their meals by electricity, a demand will have arisen which may perhaps be fostered into something worth considering. Until this happy state of affairs comes about, I fear that the demand for motive power in English residential and semi-residential districts

must remain a factor practically negligible in the calculations of the engineer.

Whether in a purely manufacturing district it may ever be found to pay to put down a central power station and transmit power to factories, each of which would replace its steam engine and boiler by an electric motor, is a question about which there is a good deal to be said on both sides. I have already indicated the lines along which I believe this matter will settle itself.

Electric Lighting.—I pass now to the last and largest section of my subject, the question of public Electric Lighting from the point of view of the Mechanical Engineer. From the side of the Public, that is of the users of electric light, the essential points are simple: namely that the light should not visibly flicker; that it should not be below the declared pressure, nor very much above it; that it should be available at all hours; and of course, most of all, that it should never go out! But any notions one might have that, in consequence of the simplicity of this final result, the means of attaining it would also be simple, are speedily dispelled by a consideration of the facts. It is, alas! not sufficient to provide a shed, a boiler, a decently governed engine, and a dynamo or alternator; and many and sad have been the disappointments in consequence. The fact is that, although the final result to be attained is always the same and is always extremely simple and straightforward, the conditions under which that result has to be obtained are always varying, and are not only extremely complex in any one place, but are also different altogether in each different place. To members of this Institution however I need not point out that this is not any cause for grumbling; the more difficult and complicated the problem, the more chance there is for the engineer in working out its solution.

I will consider first those variations which are entirely beyond the control of the engineer, *i.e.* the variations of load; and afterwards those which are within his power, *i.e.* variations in the working of the station. To those of you who have practically to do with these matters the variations I have to speak of are absurdly familiar;

but to others—probably the majority—they are still sufficiently unfamiliar to be of some little interest. I have therefore prepared diagrams which may illustrate them.

Diagram Fig. 1, Plate 41, shows the variations of output of a lighting station during a whole year. Each vertical division stands for four weeks. Irregularities are due to particularly foggy weeks, or to weeks in which public holidays occur, such as Easter and Whitsuntide. For the rest, the curve follows pretty obviously the changes in daylight, except that the minimum occurs not in the very middle of the summer, but during August, in consequence of the large number of private houses which are shut up at that time, while the days are still too long to require the use of any artificial light in shops which close at seven o'clock. This diagram corresponds to the output at the Davies Street station of the Westminster Electric Supply Corporation during 1893. The great excess in the last quarter over the first is to a considerable extent due to the larger number of lights which were on circuit towards the end than at the beginning of the year. The great drop in the last week of all is due to the fact of that week including Christmas Day and Boxing Day as well as a Saturday and Sunday.

Diagram Fig. 2, Plate 41, shows the variations within a week, each vertical division standing for one day. Here of course the chief variation is that which occurs on Saturday and Sunday.

Diagram Fig. 3, Plate 42, shows the variations occurring within one day, the vertical divisions each standing for one hour. In this diagram three days are actually shown, one in December, one in August, and one in June; and it will be noticed that the three are very different. In winter there is practically always a double maximum, one occurring about breakfast time or in the forenoon, after which the load falls off in the middle of the day and reaches its full maximum towards evening. In the summer time the morning load disappears altogether, and there is only one maximum, which occurs much later than it does in winter. In fact I have noticed that in London the average time up to which people use electric light is fully an hour later in the summer than it is in the winter—a somewhat interesting fact in sociology. In August the "peak" of the diagram becomes a

minimum, the private houses using no light because they are closed, the shops because the days are still too long.

The dotted line in Fig. 1, Plate 41, shows in rather an interesting fashion that the maximum load and the maximum output by no means vary together. The maximum load is much more constant than the maximum output, and does not vary nearly so fast or so much. The quantity which chiefly varies is the time during which that load lasts; and this time is of course dependent on the hours of sunlight, or more particularly on the interval between sunset and closing or bed-time. The curves I have given in Fig. 1 are both for London, and are consequently much affected by the London "season"; no doubt very different curves would be obtained in other places.

Besides the variations shown in these diagrams, it is right that I should mention one or two others. An important class of variations are those which may be said to be due to latitude. In a place as far north as Aberdeen, for instance, there is practically no night for two months in the year; and for a much longer time than this no lighting whatever is used in shops, and hardly any in private houses. On the other hand, the hours of lighting in the winter are proportionately longer than in the south. The effect upon the annual output diagram would be not to alter its area considerably, but to thicken it up in the winter and reduce it very much in the summer. As an illustration of northern loads I have shown in diagram Fig. 4, Plate 42, load curves for a winter and a summer day, taken at a little station which was running in Glasgow supplying offices some two years ago.

One set of variations which puzzles and troubles the engineer very much is the varying amount of light thought necessary by people in different parts of the country. No doubt this depends to a considerable extent upon the nature of the premises in which the light is used; but even this is hardly sufficient to explain the whole of it. In a purely residential district in London, for instance, the average energy used per annum is only about 12 units per lamp wired. In a mixed district like that of the Westminster Company it is about 16 units per lamp. In a very rich district containing many clubs, like that of the St. James's Company, one is not surprised to

find that it amounts to 22 units per lamp. But one is on the whole surprised to find that in Newcastle it should be as much as 25 units, and in Leeds 27. It is no doubt with less surprise that one notices that the consumption of 38 units per lamp per annum, which existed in Exeter when current was paid for by contract and not by meter, was exactly halved as soon as consumers were made to pay for the amount which they really used!

There is one set of variations which, unlike all those mentioned above, is to a certain extent under the control of the engineer. I mean the variations on the two sides of a circuit which is arranged upon a three-wire system. Here of course the engineer in the first instance endeavours to connect about the same number of lamps wired on each side of the system, and to see that the balance is approximately right, not only over the whole system but over each small section of it. To this extent he can control the case. But in spite of all the care that may be used in this matter, a three-wire system may often be greatly out of balance for a few minutes at a time, owing to causes which are entirely beyond the engineer's control. Rapid changes in this respect occur chiefly within the fifteen or twenty minutes during which load is coming on most rapidly in the afternoon. In a station when the load was increasing from 2,000 up to 8,000 ampères, I have frequently seen that in the course of ten minutes first the positive and then the negative side would have 400 or 500 ampères more than the other. By the use of a balancing machine, which can be transferred by a single switch from one side to the other, the case of course can be met as it arises; but it is sometimes a little surprising that the changes should be so large and so rapid.

I have endeavoured to indicate to you some of the great number of variations in conditions, in spite of which the engineer has to obtain a uniform result. All these variations, even the last to a great extent, are practically beyond his control. Some of them occur with considerable regularity, and can be foreseen; others are most irregular, and come without any warning whatever. But all of them affect greatly both the method and the cost of production. The method first, because the efficiency and regularity of supply must

be considered before the matter of economy. Any method of supply which was inevitably liable to breakdowns and interruptions would be wholly condemned on that ground alone, even if it happened to be of the highest economy. But given any one of the many methods of supply which are equally good in the result to the consumer, then that method must mainly be judged by its economy under the particular conditions in which it has to work. It will of course be borne in mind that the cost of power production in this case is not a mere 3 or 4 per cent. as in the case of a factory. It is 50 or 60 or 70 per cent. of the whole expenses, the balance being expenses of management and distribution, along with interest, depreciation, and other charges connected with capital.

As to the effect, then, of the uncontrollable variations on system or economy, the first thing which I have to point out is that their madness is not entirely without method. There are some points which are as certain as it is that all Members of Parliament will not be on one side, in spite of the fact that such a thing is in imagination conceivable! Two of these are of special importance. First of all, there will never be alight at once more than certain proportions of all the lamps which are wired, either at times of maximum or of minimum load. The highest maximum on the circuit of the Westminster Company is about 35 per cent., on that of the St. James's Company I believe over 60 per cent., of the House to House Company about 35 per cent. In Glasgow, where at present the light is solely in the region of offices and shops, the proportion is as high as 56 per cent. You will see that the proportion depends largely upon the nature of the place where the light is used. This proportion, which of course can be only an estimate in any particular place until the experiment is made, fixes for the engineer the maximum number of lamps wired for which a given horse-power will supply current.

The highest minimum is an almost equally important quantity; and in most places the engineer has to do with two such minima, one for the day hours and another for the night. In a purely residential district the night load will always be very small, and the day load will be practically nil. In the City of London the day load, in consequence

of the number of dark places to be lit, is considerable, the night load extremely small. In a mixed district like that of the Westminster Company, the day load in the middle of summer is not greatly more than the night load. It is to be noted however that the night load is practically the same all the year round, while the day load, even apart from fogs or exceptional weather, necessarily varies greatly. The highest maximum also, as we have seen, varies greatly at different times during the year, although it never exceeds a certain amount. It is also worth noticing that in general the night load on a central station will increase but slowly with the growth of the station. The first consumers who take the light are most often those who are most in need of it, who require it for dark corridors and long hours. Later on, thousands of lamps may come on to a circuit in shops, offices, and in ordinary private houses, without a single one of them being used after midnight. In an average district the day load increases faster than the night load, because out of any large number of shops and offices some are sure to have dark places requiring current in the daytime. But neither night nor day loads increase nearly as fast as the maximum evening load, which—a certain normal condition having once been reached—will increase exactly in proportion to the lamps wired. In an alternating-current station where numerous isolated transformers are used, the night load increases nearly proportionately to the day load, because of the increase of magnetising current.

Sizes of Units.—The determination of the sizes of units to be used in any station depends essentially on the probable values, absolute and proportionate, of the loads I have mentioned. It is now a commonplace, although a few years since no one seems to have thought of it, that the machinery in a station should be so subdivided that, under all sets of conditions which remain steady for a few hours at a time, it shall be possible for such machinery as is running to be kept running more or less nearly fully loaded; only in this way can much economy be hoped for. It must not be taken however that this is a mere question of arithmetic, which can readily be settled off-hand. In every case, it is to be hoped, the output of a station

will be much greater ten years hence than it is today. The engineer has not uncommonly to consider somewhat difficult *pros* and *cons* when he is called upon to provide machinery which shall be of such a type that it can allow dividends to be earned during the years of growth, and yet remain still suitable in the time of maturity.

It is further to be remembered that this question of the choice of size of unit is altogether modified in the cases where condensing plant is used instead of non-condensing. The reasons for this I will not discuss here; I had a good deal to say about them in a recent discussion at the Institution of Civil Engineers (Proceedings 1893, vol. cxiv, pages 73–80). A good condensing engine uses nearly the same steam per I.H.P.-hour at any load above half output. The increased consumption per E.H.P.-hour is therefore proportionately much less than in the case of non-condensing engines, and the economical importance of fully loading the machines is correspondingly minimised in stations where condensing plant is employed.

The question of size of unit leads naturally to that of the necessary magnitude of reserve in any case. I think this is a simple matter, but no doubt it is sometimes wrongly treated. To make the reserve bear a fixed proportion to the total plant, for instance, is a method which can only possibly come right by a fluke. I will not argue for the necessity of a reserve; that appears to me to be beyond any argument. The reserve is required for two purposes: to provide against breakdown of plant; and to provide against accidental increase of load on special occasions. It is in the primary conditions of the case that the light absolutely must never go out, even if a machine wholly breaks down at the time of full load. From this it follows as a mere matter of arithmetic that the minimum of reserve must be a unit equal in size to the largest unit in the station, so as to be capable of taking its place if it breaks down. I should have thought that it went without saying that a machine of 100 H.P. could not be a reserve in a station where other machines were of 200 H.P., had it not been that I have seen it often stated that it could be. If an engineer considers that the winter, when the full load is liable to come on at any moment, is a suitable time for overhauling his plant, it is obvious that the reserve must be at least

double the minimum which I have mentioned. Indeed most engineers would prefer to have two strings to their bow, and not to know that the breakdown of one machine would, as long as the breakdown lasted, absolutely use up the reserve they wanted to keep in case of specially heavy load coming on. This however is a question of degree of caution, and some would say also of nervousness.

Those questions about the running of a lighting station which are essentially matters of mechanical engineering group themselves mainly in three sections, according as they relate to (1) security, (2) efficiency of regulation, and (3) economy of working. It is obvious that the fundamental question of the choice of an electrical system in any particular case connects itself with all three; but this fundamental question I do not propose to discuss here, partly because it is not a matter which can be discussed in a few words, and partly because it is to so large an extent an electrical matter that it does not fall well within the scope of my present address.

Security.—Of the three points, I have put security first, because no doubt the absolute certainty that nothing short of a boiler explosion or of the burning down of a station shall stop the supply of current is really the first condition of supply. Clearly with any machinery the burning of an armature, the seizing of a bearing, or the breaking of a shaft, is a possibility which may have to be faced at any moment. Such things seldom occur—very seldom happily; but sooner or later one or other will come about, and the engineer in charge has to be provided with means for preventing any such accident from having more than the most transient effect on his light. Of course the existence of proper reserve plant, such as I have already mentioned, is the first necessity of the case. Scarcely less important however is the necessity that such reserve should be almost instantly available. Where all the plant is running in parallel, *i.e.* where all the dynamos or alternators are working straight through the same pair of omnibus bars on the switch board, it will often happen that the other machines which are at work may of themselves be able, at least for a few minutes, to take up the load of the one which has broken down, and so to allow time for another machine to get started. It may

well happen however that these machines may be themselves running nearly at full load, and that the broken-down machine may have had so large a load upon it that the others cannot take it up. In any case a large machine, say 400 H.P. or more, cannot be started and got on circuit in a few seconds; and seconds are of importance in these cases. For this reason, in stations which use alternating currents, it is usual, and probably necessary, to have one reserve machine always warmed up and running round at half speed, so that it is merely a matter of opening a stop valve to let it start away in a condition ready for putting on circuit, although the synchronising in with the rest of the machines is unfortunately at present a matter which always causes some minutes' delay. In continuous-current stations it frequently happens that a battery is used, which can give so high a discharge for four or five minutes as to take the place—along with the machines remaining on circuit—of the machine which has given way, until another machine has been started and put on. So far as it goes, this is no doubt a great advantage; but it must be remembered that the mere existence of a battery, and even of a battery quite sufficient for helping in day and night light loads, is not sufficient to ensure that the battery shall be available for help in this fashion. Two details are easily seen to be essential, when it is remembered that the failure may occur during the hours of full load. As the volts are highest at such a time, the battery must not only have sufficient capacity, but must also have a sufficient number of cells to give in discharge the full E.M.F. of the station; and this will not be the case unless the engineer has specially provided for it by an unusually ample number of cells. Secondly, the battery must have been fully charged beforehand, so as to have the maximum E.M.F. per cell available. This involves that the battery charge should have been completed during the day, before the hour at which full volts could possibly be required from it in case of any accident. A battery which could only discharge heavily at 215 volts would be practically of no use whatever as security against a drop of pressure after an accident which might possibly occur at 230 volts.

In an alternating-current station where the machines are not run in parallel, but where each alternator supplies current to its own

separate circuit or bunch of circuits, the sudden failure of a machine must instantly cause extinction of light in the circuit affected, for the fraction of a minute which must elapse before the circuit can be thrown on to other machines, or for the few minutes which it must take to get another engine started and plugged on. In a station worked on this plan however, the machine which is turning round as stand-by can be kept excited and giving the volts corresponding to its speed, and can be plugged on in readiness, so that the circuit from any machine which has broken down can be instantaneously switched on to it, and it can be run up at once to full E.M.F., without of course any of the delay which would be unavoidable if it had to be synchronised and put in parallel. It has also to be borne in mind that, where a number of alternators are running in parallel, the breakdown of one may tend directly, in certain cases, to endanger all the others—a trouble which does not exist if circuiting be used. On the other hand the circuiting system causes inevitable, if slight, flickers in the light, which are quite avoided by running in parallel. It also necessitates the use of comparatively numerous circuits, as no one can be allowed to carry more than from 30 to 50 kilowatts at a time when it is switched on or off.

It must be recognised that in one matter the requirements of security and of economy are more or less opposed. If an engineer is quite certain that, whether by the help of batteries or otherwise, he can bring his reserve into action so promptly that the worst breakdown will not spoil his lighting, he will no doubt always run each unit of his plant as nearly at its full capacity as possible. But if for any reason he cannot be so sure of his reserve, he will gain greatly in security by running his plant always so far under its maximum that he can for a few minutes distribute the load of any one unit over the rest without endangering them. But of course this is practically equivalent to underrating the whole capacity of the plant by a considerable percentage, probably 20 per cent., and consequently to increasing the capital cost of the plant per unit of normal maximum output by just the same percentage—a result which one does not wish to face.

I have spoken of possible breakdown of engines or dynamos. There are of course other accidents to be provided against. Short of a boiler explosion, the most serious of such accidents would doubtless be one occurring to a steam-pipe. The physical consequences of the actual bursting of a steam-pipe are not the matters at present under consideration. In all probability such an accident would disorganise any station, no matter how well arranged. But short of the actual bursting of a pipe, many things may happen which may render it necessary to shut down a certain portion of piping. It is generally necessary therefore to provide any lighting station with something in the nature of a ring-main system, or its equivalent, by which any engine in the station can be supplied with steam from either of two directions. In a properly arranged ring-main system it should be possible to disconnect or cut out of use any section of steam-pipe which may be giving trouble, without stopping a single engine. Of course it is not necessary to provide pipes so large that under these conditions there should be only the normal drop of pressure between boilers and engines. One can put up with an extra drop without grumbling, if it occurs only under these circumstances. It is inevitable, in order to reach the required degree of security in this matter, that the steam-pipe should be fitted with a large number of valves; and these are undoubtedly objectionable if only on account of the considerable loss by radiation which is almost inevitable from their covers and flanges. But after all, the making of good steam joints in large pipes at 150 lbs. pressure is nowadays a simple matter; and the unavoidable complexity of the arrangement is more than counterbalanced by its usefulness.

The duplication of the steam-pipes must obviously extend to the boilers as well as to the engines. The hanging up of a safety-valve, the blowing of a mudhole joint, the bursting of a tube, or any one of half-a-dozen other such accidents, may put a boiler suddenly *hors de combat*. It must be possible therefore, at the shortest notice, to cut out any boiler without interfering with the working of the rest. Fortunately boilers can be forced more readily than engines or dynamos, and such an accident could almost always be met

by somewhat forcing the remaining boilers. Reserve in boilers stands thus in the same position as reserve in machines, except in so far that the boilers can be more easily forced, as I have just pointed out. With boilers however, as regards security of working, there comes in an even more difficult question than that of reserve, namely that of readiness for emergencies other than breakdowns. Even in London, where a fog may cause the load on a station to increase ten times in as many minutes, there is practically no difficulty in getting the engines started quickly enough. It is otherwise with the boilers, which, although so easily forced when actually in work, are terribly sluggish in getting up steam, as compared with the rapidity with which unexpected darkness used to come over London, and doubtless will come over again when the sun has recovered from its present attempt to outshine all artificial lights! At the most inconvenient time for a breakdown, namely the time of full load, the engineer knows at least that an engine or dynamo accident can hardly affect him to more than 15 or 20 per cent. of his whole work, of which at the worst a considerable portion can in most cases be taken up by the remaining plant. But the most inconvenient time for a fog to come on is at light load; and then the increase coming on in a few minutes may be anything from 500 to 1,000 per cent.! And the engineer must be able to meet this in June as much as in December, and with even less notice. Practically this means that even in summer boilers enough must be kept under steam—if not at full pressure, at something near it—to be able to take up this enormous increase of load in ten minutes, as soon as ever their fires are brought forward and their dampers opened. I am speaking here of such cities as London, or Manchester, or Glasgow. Of course I know that there are happy places like Rome or Aberdeen where fogs are unknown, and where therefore all this provision against them is unnecessary. I need hardly point out, after going over all these considerations, that it is improbable that the fuel consumption per I.H.P.-hour in electric-light stations will ever reach, or can ever reach, anything like so low a figure as has often been reached in first-class steamers, where the engines and boilers work on

continuously day and night at pretty much their most economical load, and where stand-by boilers and reserve plant and duplicate pipes are unknown.

I will mention just one more point as to security of working in a station—the feed arrangements. Here in London I have several times run considerable risk of stoppage from this cause. A duplication of feed pumps and pipes is an obvious precaution, and one that probably every one adopts. But few of us can keep water stored in sufficient quantity to last for more than three or four hours at full load; so that, without special arrangements, we are liable to be extremely inconvenienced by any accident happening to the mains of the water companies outside, which may compel them, on short notice or even no notice at all, to cut off the supply for a few hours. The best arrangements to meet this contingency vary in different places; but the engineer must not lose sight of the fact that the difficulty is one which may occur at any time, and from causes altogether beyond his control or even his knowledge.

Outside the station, the question of security comes in in connection with the mains. To a certain extent every station which uses either high or low-tension feeders has some reserve in their very number. When a company has more than one station, trunk mains led from one to the other are also a considerable security, as well as a great help to economy. Mr. Frank Bailey of the Metropolitan Electric Light Co. has carried out a most excellent ring or looped-main system on his high-tension distributors, by which he can make sure that any consumers can be supplied in two different ways round the circuit: so that any accident to the mains may cause a minimum of inconvenience to a minimum number of consumers. In ordinary low-tension distributing networks, the same result should be aimed at, although it cannot generally be obtained in what the mathematicians would call so "elegant" a manner.

Many points occur in connection with the arrangement of electric mains which might be discussed in this connection, as to the means for isolating and testing them, the desirability of putting large sections into parallel or working them separately, etc.; but these matters lie rather on the electrical than on the mechanical side of the subject, and I must abstain from discussing them here.

Efficiency of Regulation.—I have next to speak of the *regulation* of an electric lighting station, as forming along with its *security* the two matters which chiefly affect the consumer of electrical energy. All that the consumer cares about is that the pressure in his house should be steady, and should be not less than its nominal value and not very greatly above it. In all stations working on a large scale, this constancy of pressure in the consumers' houses necessitates a constantly varying pressure at the station, in order to make up for the loss of pressure in the mains, which is itself—wholly or in part, according to the system of supply—dependent on the amount of current passing through them. In an ordinary alternating-current station the pressure at times of maximum load exceeds that at times of minimum load by about 5 or 6 per cent. In an alternating-current station with low-tension distributors the excess may be about 12 or 15 per cent. In an ordinary low-tension station with three-wire system it may often be 20 per cent. The actual figure of course depends on the current density permitted in the copper; but the figures I have given illustrate the sort of percentage which different engineers have found it advantageous to adopt on a large scale.

The primary requisite for proper regulation is obviously enough that the engineer shall know the actual value at each instant of the pressure which he desires to keep steady. In every case where low-tension distributing mains are used, this pressure is the pressure at certain feeding points or at certain sub-stations; and it is best known at the central station by direct indication, by bringing back pilot-wires or potential leads from such points direct to the station, and connecting them to suitable voltmeters there. In these cases the regulation consists in so running the machines that the pressure indicated by these voltmeters is always kept at the desired amount. What appears to me a less satisfactory method is sometimes adopted, namely determining by calculation or by experiment the loss of pressure corresponding to each output, adding this loss to the normal pressure, and regulating the dynamos to the corresponding sum, transformed if necessary. Apart from the fact that in this case the pressure actually received by the consumer is only estimated and not really measured—so that the thing measured is not

the really important quantity—there is the additional drawback that the regulation has to be adjusted to a varying quantity instead of to a constant one, and is therefore less likely to be thoroughly satisfactory.

In cases where distribution is by high tension with isolated transformers, there is of course no direct means for keeping the pressure constant in the consumers' premises. If the distance between the nearest and the furthest consumer on any circuit is much less than the distance from the station to the nearest consumer, there may be a reasonably good regulation by the indirect means I have just described. Where the distance from the station to the nearest consumer is small in proportion to the distance from the nearest to the furthest, no such regulation is practically possible; and in fact in these cases the section of the copper must be made so large as to reduce the drop of pressure within negligible limits.

By one or other of the methods which I have mentioned, and preferably no doubt by the use of pilot lines, the engineer in the station knows to what pressure he is to work. In every case the station must work at a varying pressure, although in some instances the variation may not be great. The highest pressure must occur always at the times of greatest load. Several means are at the disposal of the engineer for varying this pressure. Best of all I think, as being most convenient and most easily controlled, is the provision of sufficient additional resistance in the fields of the dynamos or exciters to enable the magnetic field to be altered by the mere moving of a switch having many contacts. Of course to a certain extent this method wastes energy; but the quantity so wasted is so small in proportion to the whole that it is not too high a price to pay. The switches can be placed upon the switch gallery so that the whole of the regulation may be done by the man in charge there, and be quite removed from the control of the engine-drivers. In order that this method may be satisfactorily carried out, the engines must be so arranged that they can be run entirely upon their governors, the stop-valves being opened fully as soon as the machines have taken up any load. In this connection it is worth while noticing that, for continuous-current machines, constancy of speed—which is

of course to be distinguished from steadiness of speed, quite a different matter—is not in itself a thing to be insisted on in the least. The governor must be so set as entirely to prevent the engine from racing in the case of a sudden short-circuit or other breakdown. But apart from this, an alteration of five per cent. or more is not a matter of the least moment. In fact for practical purposes it is generally better that the governor should not be too finely set. Of course it may happen that any one engine may have to run at any point throughout nearly its whole range of power at the same electrical pressure. If therefore the governor is so arranged as to allow of a drop in speed at full load, the field resistance must be so proportioned that, notwithstanding this drop, it can either keep the pressure constant or allow it to be increased within the desired limits.

A much less satisfactory method of regulation is by means of the stop-valve, that is to say, by the engine-driver actually opening or closing his main steam-valve according to the pressure required. If this has to be done, each engine-driver must be able to see the pressure to which he has to regulate; and instead of regulation taking place by an easily moved switch in the hands of one man, it has to be carried out by the action of half-a-dozen stop-valves in the hands of perhaps as many different men. The enormous voltmeters which were made a few years ago, and which I believe are still used in America in some places, having faces so large that they can be seen all over an engine-room, were designed in connection with this particular method of regulation. Regulation by field resistance was perhaps not so well understood then as it is now. At any rate I have no doubt which method is the better on all practical grounds.

I have been speaking of efficiency of regulation so far as it affects or is affected by the gradual alterations of load, such as are represented upon the diagrams, Plate 42. At times of full load this is practically the only matter of importance, because at such times any sudden increase or decrease of load is small in proportion to the whole load of the station. But in a station where the load every afternoon is, say 1,000 kilowatts, it may easily happen that

in the early hours of the morning or during a bright forenoon the total load is little more than a hundredth part of this. In such a case the sudden throwing on or off of a motor without proper starting resistance, or even of a photographer's arc-lamp under similar conditions, may increase or decrease the actual output by 20 or 30 per cent. or even more. Such variations are most often excessively sudden and of extremely short duration, so that they are particularly difficult to regulate for; and one must be thankful that in the nature of things they can occur at times when a little flickering of the light is not noticeable. In stations which are able to use batteries, there is no doubt that the battery acts practically the part of a flywheel in respect to these rapid variations.

Economy of Working.—I now come to my last section, namely that of economy of working a station, still looking at the matter, of course, from the point of view of the mechanical engineer. Economy of working covers two sets of questions. There is first the reduction of direct cost of coal, oil, stores, water, and maintenance per unit or per horse-power-hour; and secondly, the obtaining of the greatest possible ratio between the net useful and the gross indicated horse-power. Taking these matters in their order, the question of coal naturally comes first. In an electric-light station the cost of coal averages not far from four-tenths of the total working expenses. While however this matter is so important, it is yet one on which so much has been said and written that it need not detain us long. There is no one type of boiler, at least I do not know of any, which is better than all others under the conditions of an electric-light station. Indeed I would go so far as to say that from the point of view of economy there are five or six types of boiler which with equally good stoking will yield equally good and in every respect first-class results. Of course any type of boiler may be badly arranged or badly proportioned, may be under-worked or over-worked; but if an engineer is not capable of so proportioning the boilers of whatever type he adopts as to give thoroughly good results, or of finding out whether his results can be improved, he

had better at once take to some business which is less complicated than that of scheming an electric-light station. It may no doubt sometimes be necessary, in order to get a specially large output from a boiler, to provide it with one of the thousand infallible nostrums for that purpose. So far as my own experience has gone however, I think that almost anything can be done with a really well-designed boiler, if only the engineer in charge knows how to handle his dampers, and how to deal with his particular fuel under the conditions where coaxing is required. I have lately had some remarkable illustrations of the way in which a particular boiler could have its output increased 60 per cent. by the application of certain particular apparatus to it; and an exactly similar boiler could then, when the stoker had found out how to manage his fires, give exactly the same increase in output without any change being made in it whatever!

One thing which tells greatly against the economy of an electric-light station in respect to its evaporation per pound of fuel is the circumstance that, during all day in many places, fires must be kept alight and pressures up in boilers which are capable of giving eight or ten times the actual output; and also that in all stations much fuel must be expended in getting boilers ready for the heavy load which comes on only once in 24 hours. These stand-by losses are not, as one would think, losses which get less as the output of the station increases; for the proportion which the stand-by boilers will bear to the boilers actually used will be practically constant, whatever the output of the station. I have found that the total stand-by losses can be reduced in some cases to under 8 per cent. of the total fuel. Below this I have not yet succeeded in going, although I hope a lower ratio will be obtained in the future. I am afraid it is often considerably more than 10 per cent.

A far larger proportion of fuel waste in a station occurs I believe through causes beyond the boilers than in the boilers themselves; that is to say, it is much more easy to get a good evaporation per pound of coal than a small consumption of water per indicated horse-power. Of the causes which contribute to this, the first is undoubtedly the great loss which occurs by condensation in

the steam pipes, and by leakage through drains and other valves, before ever the steam gets to the engines at all. This is probably much greater in proportion in an electric-light station than in most other places, because the requirements of security which I have already discussed necessitate the use of so elaborate a system of steam-pipes, much more elaborate than is found in any other works. Not only does this system of steam-pipes present a large radiating surface, and in various ways offer particular facilities for cooling the steam, but also the absolute necessity of keeping the pipes clear of water at all times, so that any section of them can be used safely at a moment's notice, involves the use of drain pipes and cocks. These necessary adjuncts to a system of steam-pipes, along with the apparatus which we call by courtesy steam-traps and use in connection with them, are a continual source of waste and annoyance to the engineer. The drain cocks get left open, or if they are shut they leak themselves open; the steam-traps require more looking after than the whole of the rest of the machinery put together; and altogether the whole system of pipes, drains and traps, probably costs us in many cases 10 per cent. of our whole fuel. In some experiments which I recently had made I have found the proportion to be 8·8 per cent., and I have reason to think that it is often far greater. I know of no heroic remedy which can be applied to the matter. Probably we have not in general paid sufficient attention to the proper covering of the pipes, including their flanges and the flanges of the stop-valves. Certainly we have somehow not succeeded in obtaining steam-traps which will really act with any approach to permanent satisfaction under the trying conditions of every-day work. I hope that the use of superheated steam may be found largely to reduce this particular cause of waste. Apart from this matter I know no reason why any engine in an electric-light station should not work every day and every hour at exactly the economy which the same engine reached on special trials made at the same load under the strict conditions of a specification. I have in fact on many occasions compared the running of engines in this way with the running of the same engines at the same loads on their original tests. When I have

subtracted the amount of steam used for the feed pumps—itself a quantity which is often altogether disproportionately large—the difference was never greater than I have found to be covered by the condensation losses which I have mentioned. Of course it is necessary to remember that engines working in a central station at varying powers cannot be expected to give average results equal to those obtained at full power on trial. The results should be compared on the basis of tests at corresponding powers; and in order that this comparison may be carried out, I always have a series of graduated tests made before taking over machinery.

After the cost of coal comes the cost of oil, water, and stores. These three items together cost on the average about one-fifth as much as the coal alone. Not much can be said in circumstances like the present on the question of economy in this part of the expenditure, which really depends altogether on the good management of the engineer in charge. Such matters as filtering the lubricants and using them over again, and preventing all needless waste of water, are obviously to be considered. It is perhaps generally sufficient for the engineer to find out the lowest cost attained under these heads in any other station, and to believe he can do a little better if only he tries hard enough. Cost of repairs and maintenance, still more than that of oil and stores, is one about which little can be formulated. There is no one type of engine or dynamo, so far as I know, that can be definitely said to be ahead of all others in respect of the fewness of its repairs. There are several types of machine which in the hands of careful engineers certainly give very good results: although it is somewhat difficult to compare the published figures under this head, on account of the number of electrical stations which are still wholly or partially in the hands of their contractors, and in which therefore the full amount of repairs does not appear in the accounts.

I have mentioned that the economy of a station depends on two sets of considerations, namely the actual quantity of fuel, stores, etc. per indicated horse-power-hour, and secondly the actual relation between the useful power and the gross power. It is obvious that it would be of no use to save 10 per cent. on the coal per I.H.P.-

hour if that saving involved the use of machinery whose mechanical efficiency was 10 per cent. lower than it would otherwise be. This brings us face to face with the question which is always one of the most important to the engineer: namely, when he has got his horse-power in his engine as cheaply as possible, how to arrange so as to utilise the largest possible proportion of the horse-power thus obtained. The utilised horse-power is represented, in the case of an electric-light station, by the energy passing through consumers' meters and paid for by them. Between this useful horse-power and the indicated horse-power of the engine there come, first the loss in the engine itself, then the loss between the engine and dynamo, thirdly the loss in the dynamo itself, and fourthly all the losses between the terminals of the dynamo and the consumers' meters. As to loss in the engine itself, this does not appear to vary much in different types of engines of first-class make. Approximately it may be taken as about 10 per cent., sometimes a little less, of the full power of the engine, and as remaining nearly constant at all powers as long as the speed is constant. Thus the mechanical efficiency of an engine which is 90 per cent. at full load, will be only about 80 per cent. at half load. The efficiency of a dynamo at full load is much higher, it may be as much as 95 per cent., and may be still 90 per cent. at far below half load. Thus the ratio of electrical to indicated horse-power in a first-class steam engine and dynamo may be 85 per cent. at full load, and something like 75 per cent. at half load. This assumes that the engine drives the dynamo direct, and that there is therefore no loss in transmission between them. I must confess that it remains a complete puzzle to me—a puzzle of which I have never found any solution—why engineers should wish, in addition to these practically unavoidable losses, to spend certainly 5 per cent., and on the average probably much more, of the whole power in their station, in moving ropes or leather belts which have nothing whatever to do with the ultimate result, and which take up an enormous amount of space. The true solution of the matter really appears to me to be the use either of quick-running engines, as is so common in this country, or of slow-running dynamos, as is so commonly

the case on the Continent. I am of course speaking here of driving by steam engines, not by gas engines, in which latter case a number of other considerations come in.

As most steam engines take practically the same power *per revolution* to drive themselves, it is obvious that at low powers an increase of mechanical efficiency will be obtained by running at a lower speed than that used for full power. This of course requires an adjustable governor specially arranged, and a wide range of control in the field regulation. But I think it is worth doing in many cases.

The losses between the dynamo terminals and the consumers' lamps are, in a low-tension system, simply the losses in the leads. In a high-tension system they cover not only the losses, in general very much smaller, in the leads, but also those in the transformers as well. This is not a place nor a time for entering on a discussion of the relative merits of high and low-tension systems—a matter which, by anyone who is not a partizan of one or the other, could certainly not be adequately discussed in any time short of the whole of that occupied by this address. Moreover I need hardly point out that the choice of a system cannot possibly rest upon any one single point, such as the relative magnitude of the losses from a single cause. At present, so far as the figures to which I have access go, it may be interesting if I mention that, in the case of a low-tension system where the maximum proportion of loss in the feeders is allowed to reach 20 per cent. or thereabouts, the actual average loss of energy throughout the whole year amounts to about 10 per cent. This is of course entirely due to ohmic resistance of the feeders themselves and of the network. I have no statistics by which I can compare feeder losses only in an alternating-current system with the figure I have just mentioned; but so far as those figures go to which I have access, apparently the total losses both in mains and transformers in a high-tension system are not less than 25 per cent. of the energy generated. It is probable, indeed I think it is certain, that this figure will be very considerably reduced where banked transformers are employed with low-tension distributing mains. I hardly think however that it can be expected the total losses will ever be so low as with a low-tension system.

I have already alluded to the extent to which the economy of a station is affected by the average load at which its units are run. To attain the greatest economy it is obviously advisable that the machines actually at work at any moment should all be as nearly as possible fully loaded. The extent to which this can be actually reached in practice is shown in diagrams Figs. 5 and 6, Plate 43. In one of these it will be seen that the average load during twenty-four hours is 78 per cent. of the load which would have been reached if the same machines had run the same number of hours, each at its full power. In the other the percentage is 58. What this particular percentage may be depends always on the exact relations between the load and the size of the units, and therefore in any station will vary greatly at different times of the year. It is not at all as easy however as has often been thought to make the "load factor"—using the expression in the sense of the above ratio—very high. I find it difficult enough in many cases, even with the use of comparatively numerous units, to keep it up to an average of even 65 per cent. Of course it has to be remembered that, whether or not it is economical, the station engineer has to make certain that he has sufficient plant running to take up the work as it comes on. It is much the less of two evils that he should have every engine running every day half an hour before it is wanted, than that once a year he should be just too late with one or two of his machines. When the system of transformer sub-stations comes to be worked out practically a little more than it is at present, I believe that this load-factor problem will be found to be even more troublesome there than it is in the engine room; and that the capacity of the transformers which the engineer will consider it necessary to keep on circuit, in order that he may always be safe against breakdown of any of them, will be considerably greater than has been often assumed.

I would only in conclusion mention one other matter. The Mechanical Engineer may be supposed to be of all others one who will most naturally take to the making of measurements of all kinds. Any passion which he may have for this has ample scope in

connection with electrical work. Electrical measurements, at least with continuous currents, can be made more easily, with simpler apparatus, and more accurately, than any other such measurements. I do not doubt that this fact has helped very much in the extremely rapid progress made during the last few years in matters electrical. Apart altogether from the more refined measurements which should be made from time to time for special purposes, there is no difficulty in getting continuous measurements, self-registered, with an average error of not more than one per cent., of the current sent out from each dynamo in a station. The average station volts can also be obtained easily with fair accuracy; and the amount of electrical energy developed at the dynamo terminals can thus be continuously measured as no other similar amount ever has been measured. This amount has to be compared with the amount of energy actually paid for, that is with the sum of the readings on the meters of consumers. Some of the electrical companies have published with their annual reports detailed electrical balance-sheets which show how small the quantity unaccounted for now is. In the Westminster Electric Supply Corporation it was over 5 per cent. in 1891, 3·16 per cent. in 1892, and was still further reduced to 1·28 per cent. in 1893.

Unfortunately with alternating currents measurements are very much more difficult and troublesome; and, consciously or unconsciously, I think this fact has, to a certain extent, hindered their adoption. There are now however alternate-current watt-meters practically free from error due to circuit induction, and capable of giving results with quite sufficient accuracy under the actual conditions of station practice. I believe that great improvements in the economy of alternate-current working will date in every case from the time when the station commences to make accurate determinations—based on something different from the engine driver's hourly entries in a log—of the true energy generated, and of the way in which it has been expended.

I am sufficiently conscious of my own weaknesses to know that it is dangerous for me to touch on the subject of measurements, especially at the end of an address which has extended to

so great a length as this. I will not yield however to the temptation, but will be content with simply having mentioned the matter. And in conclusion I will only say further that I hope the active Electrical Engineers among our members will forgive me for having spent an hour on such a plain statement of matters familiar to them, if I have by this means been able to place before our non-electrical members some intelligible account of the problems at which we are working, looked at from their own point of view.

Sir FREDERICK BRAMWELL, Bart., Past-President, said it was his privilege, as senior Past-President, to ask the Members to return their grateful thanks to the President for the Address he had just delivered. It had ended with most unnecessary words of apology, to the effect that it had dealt with matters well known to many present, and that it had been put forward for the benefit of those who were not so thoroughly acquainted with the subject. He felt quite sure that every one present, whatever might be his knowledge in the special science to which the principal portion of the address had been more particularly devoted, would be grateful to Professor Kennedy for having marshalled his facts in the order in which he had done, and for having put so clearly before them the relation which those facts bore to one another with regard to the general prosperity of a good electric station. The President had pointed out various things that were desirable, but which could not always be obtained. One was that it would be a good thing if fogs would either give notice when they were coming, or would stop away altogether, leaving the sun to exert its present power of lighting. It was true that, as a shareholder in an electric undertaking, he

might feel justified in complaining of the manner in which the sun had behaved during the last year and a half, causing dividends to fall and electric current not to be consumed; but otherwise, as regarded the working of the station, irrespective of the money question, it would be an advantage to know when a fog was coming. With regard to the question of a prompt means for meeting any sudden demand, he might recall what was well known to many present, the plan pursued at the law courts, where there was one boiler in steam, fitted with a blower which was worked off a donkey engine. There the practice he believed was that, in five minutes after the demand made by a judge or other high official, the electric lights could be in full force; and by that simple arrangement, in the absence now of batteries, this condition was always capable of being fulfilled, without any considerable expenditure of fuel during the time that the fire was banked up.

Irrespective of electric lighting, the address had dealt with the driving of tools separately by electricity, so as to supersede shafting and belting. On previous occasions he had often referred to the able engineer to whom he had himself been apprenticed, Mr. John Hague, under whose guidance and advice many years ago the Admiralty began to fit up a factory at Woolwich Dockyard with separate pneumatic or vacuum engines for each tool, to replace the shafting and riggers; but they had got only a short way through the attempt when they gave it up, and kept the shafting and riggers, as was natural. How far they would have gone if they had had electricity then at their command, it was impossible to say.

The Institution had to thank the President for his address as a whole, and for bringing so clearly and lucidly before them the condition of a rising and most important industry, and one that was well worth the attention of the Members of the Institution of Mechanical Engineers. In passing the vote of thanks he was sure they would also wish to congratulate Professor Kennedy upon the fact of his having received the honorary degree of Doctor of Laws from the University of Glasgow; while at the same time he was equally sure that the University of Glasgow might be congratulated upon having so eminent a man to join their ranks.

Dr. WILLIAM ANDERSON, Past-President, said that, as Sir Frederick Bramwell had claimed the privilege as senior Past-President of moving the vote of thanks to Professor Kennedy for his Address, so did he, as junior Past-President, claim that of seconding it; and he was sure that all the Past-Presidents between the senior and the junior would have done so with equal appreciation of what they had just heard. Professor Kennedy was himself an illustration of what a thoroughly trained and educated mechanical engineer could turn his hand to. Thoroughly well and scientifically educated, he had served his time, as he had told them, in one branch of the profession; he had then further educated himself thoroughly by educating others, than which he knew of no better plan; and now he was able to take up an entirely new branch of work, as if it were natural to him. A thoroughly educated engineer could turn his hands to anything that came before him, because he had within himself the foundations of engineering science, when he had a grasp of all the sciences which contributed towards it. He had great pleasure in most heartily seconding the vote of thanks which had been proposed by Sir Frederick Bramwell.

Sir FREDERICK BRAMWELL said the motion was "that the thanks of the Members of the Institution be voted to the President for his Address, and their congratulations be offered to him upon his reception of the honorary degree of Doctor of Laws, recently conferred upon him by the University of Glasgow."

The motion was carried with applause.

The PRESIDENT thanked Sir Frederick Bramwell and Dr. Anderson and the Members of the Institution most sincerely for the kind way in which they had spoken of and received his Address. If anything could have added to the pleasure with which he received the vote of thanks, it would have been the fact that the "senior" and "junior" Past-Presidents were the two gentlemen who had spoken so kindly.

DESCRIPTION OF THE GRAFTON HIGH-SPEED STEAM-ENGINE.

By Mr. EDWARD W. ANDERSON, of Erith.

The simple and ingenious single-acting High-Speed Engine forming the subject of the present paper is the invention of Mr. Henry Grafton, and its construction is illustrated in Figs. 1 to 5, Plates 44 to 47. These show the general arrangement as designed for working vertically, which is the only form at present made; though there is nothing to prevent the same principles from being applied to horizontal engines as well. The leading idea of the design is to combine the essential qualities of a good high-speed engine—namely economy of consumption, and high speed without vibration—with simplicity of construction and fewness of moving parts. The size of engine shown in the drawings is that having a single cylinder 12 inches diameter with $6\frac{1}{4}$ inches effective stroke.

General Construction.—The engine consists of a bottom casting B, Plates 44 and 45, arranged for bolting down to masonry or to a bed-plate, and having at the two ends recesses to take the bottom brasses of the crank-shaft bearings. Upon this is bolted another casting A, having at the ends of the bottom flanges corresponding recesses for the upper brasses of the crank-shaft bearings. Facings are provided on the sides of these two castings, such that two large doors D can be put on for closing up the lower part of the engine altogether: so that the crank-shaft C may run in an oil bath, and yet can be readily examined in a few minutes by removing one or both doors. The position of the doors is so arranged that the necessary amount of oil does not rise above the bottom edge of the openings; so that, when the level is right, no oil need be run out before removing either or both of the doors.

Cylinder.—The upper casting A has the cylinder formed in it by means of two loose liners shrunk or forced in, one from each end, till they nearly meet, Plate 47. The space left between them forms the steam admission port S; and as its width is the circumference of the cylinder bore, its length is only required to be small, in order to get a large area of opening. Communication with the steam-pipe is effected through an external annular channel in the casting, Figs. 1 and 4, directly surrounding the space or admission port. At a little distance from the steam port the upper liner has a circle of holes drilled through it, which open into a similar external annular channel E communicating with the exhaust branch, Figs. 1 and 3.

Pistons.—The liners are open at both ends, forming a cylinder without covers, Plate 47, in which two cast-iron pistons P and V reciprocate in the following manner. The lower P is an ordinary trunk-piston of somewhat peculiar shape, and has a connecting-rod attached, working upon the centre throw of the crank-shaft, Plate 45. The upper piston V is likewise of peculiar form, and serves both for a piston and for a valve. It is essentially a short cylinder, having a strong diaphragm across the middle of its length; and just below the diaphragm a circle of holes is cast through the rim of the piston, which communicate therefore with the space between the two pistons. The diaphragm has a hemispherical recess bored out in it, which is lined with white-metal, and receives a steel ball attached to a cross-head; the latter spans across the cylinder, and acts on two outer throws of the crank-shaft, by means of a connecting-rod attached to each end. A suitable cap prevents the ball from leaving the hemispherical recess in the piston.

Principle.—The principle upon which the new engine is based may be best understood by imagining an ordinary single-acting engine having a single cylinder 12 inches diameter with $6\frac{1}{4}$ inches stroke, but having a slide-valve 40 inches in breadth, travelling $3\frac{1}{2}$ inches, and working over ports about 38 inches wide by $\frac{1}{4}$ inch long; the angle of advance of the eccentric being $67\frac{1}{2}$ degrees, which with the necessary lead would give a distribution of steam such as is shown in the valve diagram, Fig. 8, Plate 49. Such an engine would of

course be a practical impossibility, not to say a monstrosity, in view of the excessive friction of the slide-valve and the huge waste spaces in the ports and passages. For high speed it would be quite impracticable, on account of the enormous weight and momentum of a slide-valve of such proportions. Nor would a piston-valve of the same stroke and giving the same openings do any better, as the waste spaces would be still greater than with a D slide-valve, although the excessive friction would be absent; such a piston-valve would require to have a diameter equal to the diameter of the engine cylinder.

The new engine however has all the advantages without any of the defects pertaining to the imaginary engine just mentioned; and moreover it is even free from the unbalanced moving weights and the waste spaces of a simple engine of ordinary design taking steam during nearly the whole stroke. Firstly, as regards waste spaces, the steam is cut off close to the very bore of the cylinder, instead of at a distant valve-face with long or large passages between. Secondly, the weight of the piston and the weight of the piston-valve, instead of each alike being wholly unbalanced as in the imaginary engine, act in the same line and for the most part in opposite directions, so as nearly to balance each other, with the result that the unbalanced moment is small. Thirdly, the valve, instead of being a moving part that is idle as regards the transmission of power, performs the same function as an ordinary piston in applying the elastic force of the steam to rotate the crank-shaft; and it does this to even a greater extent than what may be termed the piston proper, namely the lower piston. Fourthly, the valve friction is no greater than that of an ordinary piston-valve of the same dimensions and stroke.

The engine thus consists essentially of two pistons working in the same cylinder, and for the most part in opposite directions, coupled to cranks on the same crank-shaft. The upper piston acts as a steam-distribution valve, working over circumferential steam and exhaust ports in the cylinder: it thus forms a piston-valve working in the cylinder itself as its valve-chest. If the cranks were exactly opposite each other, and the obliquity of the connecting-rods were disregarded, and the moments of the two pistons were equal, a perfectly balanced engine would be realised. But as the timing of

the movement of the pistons with regard to each other, and of the valve-piston with regard to the cylinder ports, would be symmetrical in both the outward and inward strokes, such an engine would be equivalent to an ordinary engine having the eccentric set diametrically opposite to the crank. Consequently the periods of admission and lead would be equal to each other, as would also the periods of expansion and compression: with the result that the engine would run indifferently in either direction, but the power developed would be small, being only the excess of the power developed in the expansion above the power absorbed in the compression.

In order that the power developed may be commensurate with the size of the engine, this symmetrical arrangement is disturbed, the cranks being placed at an angle, preferably 135°, so that the time of the movement of the pistons in regard to each other does not coincide with that of the movement of the valve-piston with regard to the cylinder: that is to say, when the two pistons are at their greatest or least distance apart the valve-piston is not at the end of its stroke. This difference of timing gives the same distribution as would be obtained in an ordinary engine having the same difference of timing between the piston and the valve. In comparison with an ordinary engine, the port in the upper or distributing piston, as it may be called, is analogous to the steam port of an ordinary cylinder; and the surface between the steam and exhaust ports in the cylinder is equivalent to the cover face of an ordinary slide-valve: the upper edge of the steam port S, Plate 47, represents the steam edge of the ordinary slide-valve, and the lower edge of the exhaust port the edge of the exhaust cavity in the slide-valve; but with this difference that, whereas in an ordinary engine the cylinder port is stationary and the valve is moved, here it is the valve which is stationary and the cylinder steam port that moves. It will be seen that the engine will now run in one direction only, the leading crank being that of the valve-piston, as shown by the arrow in Plate 44.

Length of Stroke.—The effective stroke of the engine would equal the sum of the strokes of the two pistons, if their cranks were

diametrically opposite each other. It would be nil if the cranks were coincident in angular position and of the same radius, since the pistons would move together as one; and if the cranks coincided in angular position, but were of different radius, the effective stroke would be equal to the difference of the strokes of the pistons. It is obvious therefore that the effective stroke, that is, the movement of the pistons in regard to each other, is equal to twice the length of the line joining the centres of their crank-throws, measured in the plane of rotation, disregarding the obliquity of the connecting-rods. The length of this line therefore corresponds with the effective crank-throw; and the angle which this line makes with the crank controlling the movement of the valve-piston is the complement of the angle of advance of this effective crank considered as an eccentric actuating a valve. The formula for calculating the effective stroke c is the following:—given the crank radii a and b of the two pistons, forming the two sides of a triangle and containing the angle θ, then the third side or hypothenuse c, which is half the effective stroke, is found by the equation $c^2 = a^2 + b^2 - 2\,ab \cos \theta$.

Steam Distribution.—The theory of the engine will be more fully understood by reference to the valve diagram Fig. 6, Plate 48, which is the one used by the inventor. The two concentric circles A and B represent the paths of the crank centres about the crank-shaft O; the larger B represents the crank path of the valve or upper distributing piston, and the smaller A is the crank path of the lower piston. The position shown of the cranks OA and OB is that which corresponds with the commencement of admission. The line AB joining the crank centres represents the effective crank; and the largest circle C, struck with this radius, represents the path of the effective crank about the valve-crank taken as a centre at the commencement of admission. The vertical diameter of this circle is consequently taken to represent the effective stroke line. A horizontal line AD gives the point of admission D on the vertical stroke-line. The horizontal line BB_1 drawn from the valve-crank centre B represents the admission edge of the steam port; and the vertical distance OE of this horizontal line from the

shaft axis O represents the lap on the steam side; whilst its maximum distance EF from the nearest extremity of the vertical diameter of the circle B described by the same crank is the maximum steam opening. The cut-off takes place when the valve-crank centre arrives at the point B_1 where the same horizontal line BB_1 again cuts the circle B; and if, when the valve-crank centre is at this point B_1, a line be drawn from the centre of the largest circle C parallel to the then corresponding position of the effective crank $B_1 A_1$ and cutting the largest circle at C_1, a horizontal line $C_1 D_1$ drawn from C_1 will give the point of cut-off D_1 on the vertical stroke-line. The horizontal line $B_2 B_3$ above the crank-shaft O represents the effective edge of the exhaust port; and its vertical distance OE_1 from the shaft centre O represents the exhaust lap, whilst $E_1 F_1$ represents the maximum exhaust opening. The intersection of this line $B_2 B_3$ with the valve-crank circle is consequently the point B_2 in the revolution, at which the exhaust takes place; and if, when the valve-crank centre is at this point B_2, a line be drawn from the centre of the largest circle C parallel to the then position of the effective crank $B_2 A_2$ and cutting the largest circle at C_2, a horizontal line $C_2 D_2$ drawn from C_2 will give the point of release D_2 on the vertical stroke-line. Similarly by drawing a radial line BC_3 from the centre to the circumference of the largest circle C, parallel to the position of the effective crank $B_3 A_3$ at the moment of the closing of the exhaust in the return stroke, the point of compression D_3 may be found on the stroke line. In the same way may be found any other point in the stroke, corresponding with any other position in the revolution of the cranks.

As an attempt to render the distribution yet clearer, a modified valve-diagram is shown in Fig. 7, Plate 48, in which the effective-crank circle C is drawn concentric with the circles B and A of the upper or valve-piston and the lower piston, all three circles having their common centre at O. Here the four radii OC to OC_3 are drawn parallel to the same four successive positions of the effective crank AB to A_3B_3 as in the previous diagram, Fig. 6. The points where these radii cut the effective-crank circle indicate as before the

angular positions of the points of admission, cut-off, release, and compression; and by drawing horizontal lines from them to intersect the vertical diameter of the circle, the approximate points in the linear stroke may be obtained by measurement, in percentage of the total effective stroke.

Zeuner's well-known slide-valve diagram may also be used, as shown in Fig. 8, Plate 49, which is drawn to suit the imaginary engine previously referred to, with the same steam lap of $1\frac{3}{8}$ inch and the same exhaust lap of $\frac{1}{2}$ inch as in the two diagrams already considered. Comparing the results with those obtained in Figs. 6 and 7, it will be found that all three practically agree; by measurement the cut-off is shown to take place at 25 per cent. of the stroke, release at 81 per cent., closing of exhaust and commencement of compression at 54 per cent. of the return stroke, and lead or admission at $97\frac{1}{2}$ per cent. of the return stroke. In Fig. 8 the shaded portions S and E in the two valve-circles show the necessary lengths of the steam and exhaust ports in order to get a suitable area of passage through them; and it will be noted that the travel of the valve is more than sufficient to open each of them fully.

Yet another way of regarding the action of the engine is to consider the actual motion of the lower piston relative to that of the valve; and then to see the influence that the conversion of the valve into the upper piston has upon the final result. For this purpose another Zeuner diagram has been prepared in Fig. 9, Plate 49, as if the lower piston worked in a closed cylinder, and received steam from the upper piston acting simply as a piston-valve driven by an eccentric which makes an angle of 135° with the lower-piston crank. The result is that admission of steam takes place shortly after the commencement of the outward or down stroke, cut-off shortly before the half stroke, release at about 94 per cent. of the stroke, and compression at a little less than three-quarters of the return stroke. Supposing now there are two pistons moving in precisely opposite directions, and still the same independent valve, the only effect will be that the stroke will be doubled, if the crank-throws are equal, without altering the distribution at all; that is to say, the indicator diagram will remain the same. But if the crank of the upper piston

is not opposite to that of the lower, but at the same angle to it as the valve eccentric, the distribution will evidently be completely altered; and if by a last step in the evolution of the engine the upper piston is made to act as the valve also, the new distribution is not again altered, but the engine is greatly simplified.

In order to ascertain how the upper piston with its crank at an angle to that of the lower piston alters the distribution, it is necessary to trace through the movements of both pistons during a complete revolution. In the first place the dead points of the engine now occur at different places from those of either piston alone: namely when the two pistons are closest together and farthest apart. This is evidently the case when the line joining the centres of the two crank-pins projected upon the same plane is parallel to the axis of the cylinder: which happens of course twice in each revolution, with an interval of exactly half a revolution between. With equal crank-throws the position of the effective dead points is thus behind the dead points of the lower piston to the extent of half the supplement of the angle of the cranks: that is, to the extent of $22\frac{1}{2}$ degrees when the equal cranks are at 135 degrees apart. If then the stroke is commenced from the closest position, it will be found that the two pistons at first move in the same downward direction, the upper with decreasing, the lower with increasing velocity, till the connecting-rod of the upper is vertical; after which it begins to recede from the lower piston, and the space between them increases rapidly. When the lower-piston crank has moved through about $83\frac{1}{2}$ degrees from its own dead point, or about 61 degrees from the effective dead point of the combination, the upper or valve-piston cuts off the steam. At this period the net movement of the upper piston from the effective dead point will have been much less than that of the lower piston, because the upper has both advanced and receded; and the amount of its net movement is clearly the extent that the steam port was open for the lead at the commencement of the effective stroke. Adding therefore this amount of effective motion to the motion of the lower piston, the ratio between their sum and the total effective stroke is the ratio of cut-off. The actual figures can be obtained from the diagram, Fig. 9,

Plate 49, by adding upon it the radius OB, making an angle with the axis OX equal to the difference between the position of the cranks at the commencement of the actual downstroke of the lower piston and at the commencement of the effective stroke, that is in this case an angle of $22\frac{1}{2}$ degrees. The radius OB will cut the lap and valve circles in the points C and D; and the space between these points, which measures 0·25 inch, gives the lead or the amount that the steam port is open at the commencement of the effective stroke. As it happens in this case that the sum of the steam lap $1\frac{3}{8}$ inch and the lead $\frac{1}{4}$ inch is equal to the half stroke $1\frac{5}{8}$ inch of the lower piston, the stroke circle is drawn with the radius OD, which is equal to that of the lower-piston crank; and perpendiculars to the axis OX being drawn from the commencement of the effective stroke at D and from the point of cut-off at E, the distance between these perpendiculars gives the amount that the lower piston has moved from the effective dead point, which in this case measures 1·3 inch. Therefore the combined effective motion of the two pistons up to the point of cut-off has been $1 \cdot 3 + 0 \cdot 25 = 1 \cdot 55$ inch: the ratio of which to the total effective stroke 6·25 inches is 24·8 per cent. or practically one quarter, thus giving the same result as is obtained from the previous diagrams Figs. 6, 7, and 8. Similarly the effect of the combination on any other points in the distribution may be ascertained.

None of the foregoing diagrams take account of the obliquity of the connecting-rods; and therefore in Plate 50 another is given which does so, but is somewhat more troublesome to construct. Here the path of each piston is set out geometrically as a continuous curve plotted along a straight-line base representing the angular motion of the cranks, as if the return stroke were added on to the forward stroke in the same direction, thus producing a wavy line. If these two waves are now placed together in a position equivalent to that due to the relative angular displacement of the cranks, and so that at one point in each revolution they touch, then that point will denote the position of minimum distance between the pistons, or the commencement of the stroke. It will then be possible to find the point M where the distance between the two curves is a

maximum, and this will give the end of the stroke. Moreover, if lines at right angles to the axis of the upper or distributing piston are drawn representing the port edges AA and BB, the points cut by them in the curves will give the distribution as before. The effect of variation of the crank angle can be well shown from this diagram, by displacing the two curves with respect to each other; it will be seen at once from the two dotted positions how the effective stroke alters with the angle of displacement. This diagram is the one practically used in designing these engines, and is constructed for the size having a cylinder of 12 inches diameter with $6\frac{1}{4}$ inches effective stroke.

Details of Construction.—The main casting containing the cylinder has two side vertical passages in it, Plates 45 and 46, through which the two connecting-rods from the upper piston pass down to the crank-shaft; and over all at the top a cast-iron cover is bolted, the whole engine being thus completely closed in. The lubrication is all effected from the crank chamber; the mixture of oil and water which is splashed about in all directions by the crank finds its way even up through the passages through which the side connecting-rods pass, and so on to the top piston and cylinder where it is exposed, as well as to the cross-head ball; the lower part of the cylinder gets such an abundant sprinkling that the difficulty is to prevent its being excessive. The lower piston has several distributing grooves turned in it, Plate 47, which carry up the oil to the upper parts of the cylinder and keep the whole thoroughly lubricated. Both pistons have diaphragms across them, to prevent the oil from getting to the parts in direct contact with the steam, and so causing condensation. The cross-head ball has also an oil chamber in it, which may be filled through the hand hole in the top cover, Plate 44. Drain cocks are arranged in the steam channel, and at the short zone round the cylinder which is never covered by either piston; this same zone is also the only possible place for the indicator cock to be put on. In order to prevent any pressure from accumulating in the casing by leakage, a small relief-valve R is provided in the top cover, opening to the drain or to the exhaust passages.

A sufficiently heavy fly-wheel is of course necessary; and as the cranks are not opposite, some balancing is needful to secure the best result. In the first instance, weights were put on the crank webs; but they were found to splash the oil about so much that it became desirable to remove them, and to do the balancing externally. For this purpose the fly-wheel is made use of; and it is best where possible to have two fly-wheels, one at each side, and do half the balancing in each, whereby the moments of the weights round the vertical axis oppose each other, and so produce no external effect in causing vibration.

Economy of Steam Consumption.—Among the advantages realised by this construction and principle of engine, perhaps the most important is economy of steam consumption. The engine is single-acting and non-compound, and as such it will no doubt find its chief use; but there is no reason why a combination of two engines side by side should not be arranged to work compound if desired, or possibly other plans of attaining the same end might be devised. At present simple engines only are in contemplation, up to about 80 horse-power; and the working of these only will therefore be here dealt with.

The characteristic points of the valve diagrams, which have been referred to, are early cut-off and considerable compression. Besides this, there is practically no length of steam passage corresponding with that between the valve face and cylinder in an ordinary engine; while a large port opening can be obtained with but small movement of the distributing piston. The consequence is that the points of cut-off and release are well marked, with little wire-drawing; the steam can be expanded well down; and that left in the cylinder after the exhaust port closes can be compressed right up to the initial pressure without difficulty. All these points combine to give a highly economical indicator diagram. An experiment made on the 12-inch engine working with an initial pressure of 100 lbs. per square inch at 603½ revolutions per minute, indicating a mean of 36·77 horse-power, gave a consumption of 28·2 lbs. of feed-water per I.H.P. per hour. One

of the diagrams from this experiment is shown in Fig. 13, Plate 52. Unfortunately it seems impossible to get the expansion curve free from waves, and there is little doubt that the power deduced from such diagrams is too low; this point is alluded to later on. The consumption of steam given by the diagram is 23·2 lbs. per I.H.P. per hour, and the quantity missing is therefore 18 per cent.

In this engine the steam pipes and passages are rather small, and some wire-drawing results; but another diagram from an 8-inch engine is given in Fig. 12, Plate 52, showing much less, as the passages were larger. This better proportion is now being followed in the later designs, and a still greater economy should therefore result; but it has not been possible to carry out a trial of the 8-inch engine from which the diagram, Fig. 12, is taken. It is intended moreover to steam-jacket the engines, which can readily be done without material increase of first cost; and then a still better result should be obtained.

High Speed.—The next point of merit is the capability of running satisfactorily at a high speed. The advantage of high-speed steam-engines has now been well recognized, as they provide a means of getting considerable power at a small initial cost, and are capable of being combined direct with such machines as dynamos, centrifugal pumps, and fans, without the intervention of gearing, thus avoiding the loss involved in the latter, and economising space. Obviously the higher the speed at which an engine can run, the more marked become these advantages; but on the other hand difficulties have to be met, which do not occur in engines running slower. That the engine now described is peculiarly well adapted for high speed will be seen from the following considerations.

Piston speed.—Inasmuch as each piston travels through only about half the effective stroke of the engine, it is clear that the piston speed is only about half that of a single piston working at the same number of revolutions, and giving the same power in the same diameter of cylinder. Thus even with the highest speed of revolution the piston speed is low. For instance the 12-inch engine has an effective stroke of about $6\frac{1}{4}$ inches, so that at its usual speed of 600 revolutions per

minute the speed of a single piston would be 625 feet per minute; but as the strokes of the two pistons are really $3\frac{1}{2}$ and $3\frac{1}{4}$ inches severally, their speeds are only 350 and 325 feet respectively. Hence the friction and wear are reduced; and all the effects of inertia, which depends on the square of the speed, are much less marked. Consequently the tendency to reversal of stresses on the crank-pins at the turn of the stroke can be more readily overcome, and noiseless running be thereby secured. A further effect of the short stroke is that connecting-rods of only moderate length are a considerable multiple of the stroke; and therefore the side stresses on the pistons are but small. The connecting-rods are about 8 and 15 crank-throws in length; the latter are those for the distributing piston, on which it is more important to avoid wear than on the other.

Balancing.—If the pistons were exactly opposite each other—that is, if the cranks were at 180° and of equal throw, and the weights were equal—it is obvious that, neglecting the difference due to the unequal obliquity of the connecting-rods, the engine would be completely balanced. As however the cranks are not opposite, the balancing is not complete; but it can be made nearly so by the addition of small balance-weights on the crank webs, or in the fly-wheels. Owing to the peculiar arrangement of the engine, the moments of such weights about the vertical axis neutralize one another, so that no external resultant is produced to cause vibration.

Clearance, and Compression.—Ample area of ports and passages is readily obtained without adding to the clearance. As already shown, a considerable compression can be obtained in the return stroke; and this is of great value in counteracting the inertia of the moving parts, as well as on the score of economical working.

The effect is that the 12-inch engine with $6\frac{1}{4}$ inches effective stroke can be run with ease up to 600 or 650 revolutions per minute, and the smaller sizes up to 800 or 850; and at these speeds they are quite silent, and free from all objectionable vibration.

Wear.—The arrangement is particularly adapted to run with a minimum amount of wear, from the fact already noticed that, the

angle of the connecting-rods being small, the lateral pressure of the pistons on the cylinder bore is small; and as the surface is so large, the pressure per square inch is insignificant. Thus practically the only wear is that due to the pressure of the piston rings. The crank bearings are all subjected to stress in one direction only, and are well lubricated, besides having large surfaces; and the main crank-shaft bearings themselves are largely relieved of pressure by the peculiar arrangement of the three connecting-rods, of which the two outer nearly oppose the centre one. If the cranks were quite opposite, the main bearings would be practically relieved completely of all stress, except that due to the weight of the moving parts. As it is, they are nearly so, though they will of course have some stress put on them from outside, such as that due to the weight of a dynamo armature or the pull of a belt; but there is ample surface to provide for this, and in any case the pressure per square inch will be exceedingly small. These are the only parts subject to wear at all, except of course the governors.

Indicator.—A somewhat puzzling problem to be solved in this engine is how to work the indicator barrel so that the motion may be a true one. Neglecting the obliquity of the connecting-rods, the ends of the effective stroke are reached when the line joining the crank-pin centres is vertical, or parallel to the axis of the cylinder. In these positions the indicator barrel is required to be also at the extremities of its stroke; and this consideration gives a clue to the simplest way of arranging the gear. A pin must be put on the end of the crank-shaft at a radius which will give the best stroke for the indicator barrel; and the radius joining it to the centre of the shaft must be parallel to the line joining the crank-throws. Then if the string be led off vertically to a sufficient distance, and thence be carried over a pulley to the indicator, the motion will be approximately correct. But the obliquity of the connecting-rods prevents the motion thus obtained from being perfectly true; and some modification is desirable in order to obtain greater accuracy. Moreover it is not always convenient to fix a pin on the end of the shaft: as in the case of an engine provided with a crank-shaft governor and driving a

dynamo direct. Accordingly an eccentric has been adopted, the sheave of which can be clamped on the shaft, as shown in Plate 51; and the strap has a short rod controlled in its movement by a link L, one end of which is connected to the rod while the other is centred on a fixed pin. The end of the cord is then attached to an eye on the link, and led over a guide pulley to the indicator. By turning the engine round, and stopping it at defined points of the stroke — such as the beginning, end, point of cut-off, and opening or closing of exhaust—and at the same time marking the points upon the paper on the indicator barrel, the accuracy of the gear may be readily verified. In this way it is found that, by adjusting the position of the fixed centre on which the controlling link L vibrates, a close approximation can be obtained to a true motion.

The next problem is how to get a really good indicator diagram free from the waviness already alluded to; because experiments have shown without doubt that the diagrams taken from the engine at high speeds are not by any means correct, and that the horse-power deduced from them is too low. Two indicators were tried, both of a kind usually employed for high-speed engines; but although the results from one seemed nearer the truth than from the other, neither were what they should be, even though very short strokes of the indicator barrel were used and various strengths of springs were tried. A different form of indicator is now under consideration, whereby it is hoped that some satisfactory results may be obtained.

Condensing.—It is highly desirable that an engine of this kind, especially if it is to be used on shipboard, should be capable of exhausting into a condenser. This end will evidently be attained, if the exhaust branch is connected to a condenser; but the effect will be that on exhausting a reversal of pressure will take place between the pistons, and will cause a knock on the connecting-rods, just as in a double-acting engine, which at high speed would cause a great deal of noise and wear. It therefore becomes necessary also to connect the outer casing of the engine permanently with the condenser; and when this is done, it will readily be seen that, as the pressure between the pistons never gets less than that outside them, no

reversal will take place, and the engine will run at the high speed quietly. The 12-inch engine has been satisfactorily tested in this manner, exhausting into an independent condenser; and in Fig. 14, Plate 52, is shown the indicator diagram so obtained when running at 467 revolutions per minute with a boiler pressure of 80 lbs. per square inch and a condenser vacuum of 21 inches of mercury or $10\frac{1}{3}$ lbs. per square inch.

Discussion.

Mr. ANDERSON exhibited the two pistons of one of the 6-inch engines, and mentioned that the details of the engine had been considerably altered since the drawings illustrating the paper had been made, although of course the principle remained the same. The valve diagrams shown in Figs. 6 and 10, Plates 48 and 50, were Mr. Grafton's own design; and the others shown in Figs. 7 to 9 were simply modifications of Fig. 6. He showed also the different form of indicator alluded to in page 227, which was probably known to many engineers, having been invented by Professor Perry. As shown in longitudinal section in Fig. 15, Plate 53, and in front elevation in Fig. 16, it consisted of a chamber something like a shallow pill-box, rocking on two trunnions, one of which was hollow for admitting steam into the inside of the box. The lid covering the box was a thin disc of steel secured by a screwed ring; and at a point halfway between the centre and the ring a small mirror M was fixed upon the disc. The trunnions of the box were mounted in a frame having a hollow elbow E at one end and a set-screw S at the other, whereby the hollow trunnion was kept steam-tight while rocking in the elbow. A lever L was attached to the box, by which it could be given a rocking motion from some convenient part of the engine itself. A lamp with a small hole in front of it was placed at

a suitable distance; and the image of the small hole, reflected by the mirror, was thrown upon a screen. The result was that, when the elbow E was connected with the indicator cock, and the lever L was set in motion by the working of the engine, the pressure entering through the hollow trunnion got into the box behind the disc and bulged it more or less, thereby deflecting the mirror towards the side, at the same time that it was also being deflected upwards and downwards alternately by the rocking lever L. The indicator diagram was thus traced by the ray of light thrown upon the screen; and if the engine ran fast enough, that is at more than 200 revolutions a minute, the line of light traced upon the screen was practically continuous, and the whole diagram was actually seen complete at once before the eye. The three diagrams shown in Figs. 17, 18, and 19, Plate 53, had been taken in this way, and were seen to be quite free from the waviness of those shown in Figs. 12, 13, and 14, Plate 52. When the working of the engine was altered while it was running, the indicator diagram could be seen to be altering conformably. Unfortunately however the diagrams so taken were not even yet quite what they ought to be. The difference of the back pressure in Figs. 17 to 19 would be observed. There seemed no particular reason to account for it, because the speed was almost the same in Figs. 17 and 18. It had also been found that the scale of pressure was not quite an even one; but this objection he believed could be got over by a careful adjustment of the disc and mirror. The indicator wanted yet a great deal of work to get it quite right; but whenever it was got quite right, he considered it would be found that remarkably accurate results could be obtained with it. In the discussion he hoped that something would be said by those of the members who had had experience of high-speed indicator diagrams, as to how best to get a good result. Where there was a low pressure of steam for working the engine described in the paper he had found that the clearance between the two pistons of the engine had to be made larger, in order to prevent the loop that would otherwise be formed in the diagram by the pressure rising above the true initial steam-pressure in the cylinder.

Sir Frederick Bramwell, Bart., Past-President, mentioned that in a paper read to the Institution of Naval Architects (Transactions vol. xiii, 1872, page 269) he had given the indicator diagrams he had taken from one of Mr. Thornycroft's earliest quick boats, the "Miranda," with engines running a little over 600 revolutions per minute. Those diagrams, although not perfect as regarded the uniformity of the curve, were a much nearer approach to perfection than the diagrams illustrating the present paper. They had been obtained with an ordinary Richards indicator of those days, but specially prepared by having an excessively strong spring, limiting its stroke to one inch, while its horizontal or rotary movement was also limited to one inch. The diagram cylinder was furnished with extra springs of india-rubber to the extent requisite for making it work rapidly; and the result was that diagrams were obtained, which he thought might be relied upon for accuracy of the area as a whole, because when trying the vessel at all sorts of different speeds of revolution the diagrams so taken bore the ratios one to another which they ought to bear. If they were wrong, they were wrong in equal proportions; but he thought in reality they were fairly right.

The idea of halving the stroke of an engine by putting two pistons in the cylinder, working in opposite directions, was an old one. At the Manganese Ore Works, at Rotherhithe, he remembered an engine being used, which had an upper and a lower piston of equal stroke in the same cylinder, under a mistaken notion that double power was going to be got out of the steam because there were two piston surfaces for it to act upon simultaneously instead of only one at a time; barring that original error, there were in that engine two pistons, each moving through half the length of the cylinder, but the engine had the usual arrangement of slide-valve with long passages to the cylinder. In the engine described in the paper there were no doubt some curious points. The two pistons moved in opposite directions, as in the Rotherhithe engine, practically halving the stroke; and from the way in which they balanced each other as regarded their weight, and from the various other contrivances that had been described, no doubt the engine was capable of running at a very high speed of revolution.

Attention had been called to the large port area, coupled with the small length of port, which was obtained by reason of the circumferential valve. On this point he had prepared a drawing, shown in Fig. 20, Plate 54, of an engine which he made forty years ago in 1854 for the purpose of driving a circular saw for cutting tires &c. in an iron works. It was a double-acting engine, that is, it acted in both directions; and it was extremely simple in manufacture. There was a sort of bed-plate B, in the middle of which was the exhaust pipe E. The steam cylinder C had upon its circumference at the bottom the slide-valve face, which extended the whole way round the cylinder. What looked like two opposite slide-valves in the vertical section, Fig. 20, were simply the sections at the two opposite points of the single annular slide-valve, shown separately in Figs. 21 and 22, which embraced the cylinder, and was worked in the ordinary way by means of the cross-head H and two eccentrics X. The outer casting A enclosing the steam cylinder was simply turned, and fitted to the cylinder casting at bottom and top; the boiler steam in the annular steam-chest surrounding the cylinder entered into the top of the cylinder through a number of openings all round, where the cylinder was fitted into the outer casting. In the cylinder worked a trunk piston, with connecting-rod acting upon a balanced crank. By this arrangement there was the whole circumference of the cylinder for the width of the steam port, and therefore the engine could afford to have a remarkably short or shallow port and a small travel for the slide-valve. Further the annulus above the piston was always open to the boiler, and the area of the annulus compared with the area of the whole piston was such that practically uniformity of stroke up and down was obtained. The steam in the annulus pressed the piston down while the bottom of the cylinder was open to the exhaust; and when by the action of the slide-valve the steam was allowed to get in below the piston, the steam in the annulus was pumped back again into the boiler, or underneath the cylinder. One great merit of the engine was the slide-valve; as seen from Fig. 22 it was a complete circle, which was bored out to fit the cylinder face, while the latter was turned to receive it; the whole construction was thus of the simplest kind.

(Sir Frederick Bramwell, Bart.)

At G the valve had a longitudinal gash right through it; and by putting packing into the gash the circular slide-valve could be slightly opened out, so as to make it absolutely float on the cylinder without any pressure whatever, while still it was found to be perfectly steam-tight in working. The engine ran at a high speed quite quietly. It had not been usual he thought in those days to take such elaborate indicator diagrams as were shown by the author; and in fact he had himself taken none from the engine he had just described. On being put to work, the engine drove with great efficiency a saw for sawing railway-wheel tires. Provision had also been made for expansion-valves, and so on; but in Fig. 20 the engine was shown in the crude simplicity in which it had actually worked.*

Mr. J. Hartley Wicksteed, Member of Council, said that what struck him about the engine described in the paper was that there would be a tight place in it. Looking at it purely from the mechanical point of view, it seemed to him that at the beginning of the stroke, when the two nearly opposite cranks were each so near their dead points and the two pistons were being forced apart, there would be a great amount of binding action upon the crank-pins. For if in that position the fly-wheel was taken hold of and tried to be turned round, a large amount of friction would have to be overcome which was put upon the two opposite crank-pins by the pressure of the steam; in other words, the pressure of the steam seemed at that time to be exerting a great deal of dead pressure, which resulted in friction, without having any sufficient length of arm by which to give a turning moment to the shaft. No doubt there were large surfaces and profuse lubrication, and therefore the coefficient of friction was small; but still it would be interesting to know what the mechanical efficiency of the engine was in actual working.

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* Sir Frederick Bramwell desires also to call attention to a double-piston arrangement which he saw applied to a locomotive on a plan designed in 1834 by Mr. Bodmer, by whom the plan was adapted in 1841 to marine propulsion.

Mr. Druitt Halpin considered that in the design of the engine, although the arrangement shown in Fig. 5, Plate 47, for the ball-and-socket joint looked so compact, namely dishing down the top of the upper piston so as to receive it, it would be much more in favour of the engine if the cone were turned the other way up, in the form of what was sometimes called the Swedish piston, with the ball-and-socket joint mounted on the top of the cone. That would give the advantage of avoiding what he thought must now take place, namely the continuous water-jacket on the top of the upper piston, which seemed to him to be at present a great disadvantage. Another point that struck him in looking at the drawing and the specimens exhibited of these deeply recessed pistons was that immediately on the steam being admitted, instead of its having to encounter only the cold area of a flat cylinder cover and a flat piston, the recessed construction of the two pistons exposed a much greater extent of cooling surface, which had immediately before been in direct communication with the exhaust, and must therefore necessarily cause such an amount of initial condensation as must render the engine wasteful in the use of the steam.

With a view to getting over the waviness of the indicator diagrams shown in Figs. 12 to 14, Plate 52, attention had been drawn to Professor Perry's indicator, which was certainly a beautiful instrument, although his own faith was not strong enough to trust it much; he liked an indicator which could be calibrated, and he did not see how it was possible easily to calibrate this. The trouble however could be got over he thought in another way. It arose of course from two causes, namely from the speed of the moving parts of the indicator and from their weight. Their speed could not be altered, as it naturally depended on the speed of revolution of the engine; but their weight could, and in the following way. Supposing that the whole of the mechanism usually worked from the end of the indicator piston-rod were done away with, and that the pencil were fixed directly on the extremity of the piston-rod and at right angles to it, so as to mark direct upon the paper cylinder placed parallel to the indicator cylinder, with a suitable provision for the paper cylinder to press lightly up against the pencil: then the result would

(Mr. Druitt Halpin.)

of course be that the diagrams so drawn would be only the natural height of the stroke of the indicator piston, without any multiplication by levers such as were usually employed. Indicator diagrams had only two uses: either their area was measured in a large number of diagrams taken during an engine trial for ascertaining the indicated horse-power; or else they were wanted in order to see exactly what the steam distribution was throughout the stroke, apart from the question of power. If they were taken for ascertaining the horse-power, although on the plan he was recommending they would be so small, yet their area could be accurately measured with the newer forms of planimeter now coming into use, having a glass which was marked with cross lines; by this means the area was directly measured without error. If on the other hand a magnified diagram was wanted for showing the action of the steam during the stroke, he thought it was a much more mechanical way of attaining that object if, instead of magnifying the diagram at the indicator itself from a small delicate motion and by means of multiplying levers of which the momentum could not be controlled, the small diagram taken direct in the way he had described was afterwards enlarged in the drawing office by any one of the ordinary instruments of the lazy-tongs kind, by which it could be magnified to any size desired. In that way the momentum of the indicator and the consequent waviness of the diagrams could be reduced to a minimum, and all the trouble attending high speeds could be got rid of, so far as the indicator diagrams were concerned.

Mr. Lewis Richards asked whether some information could be given as to the brake horse-power in comparison with the indicated horse-power of the engine; and also whether the temperature had been taken of the lubricant—the mixture of oil and water—at any time when the engine was running at full speed. Moreover in calculating the power of the engine from the indicator diagram, had the fact been taken into account that during two periods in each revolution one piston was acting as a brake against the other? This he thought would require some correction to be made in the power calculated.

Mr. Arthur Rigg had listened with great interest to the description of this ingenious engine, because it seemed to him to combine certain problems which always had to be faced in designing a high-speed engine. In many respects it was analogous to all other high-speed reciprocating engines ; but it had the exceptional advantage, which at least he thought was its principal advantage, that for all practical purposes one piston served as a counter-balance to the other. In every high-speed engine the piston was practically a steam-hammer, and as it came near the end of its stroke it had to be brought to rest by some means or other. In most high-speed engines it was brought to rest by compressing the exhaust steam ; and in the Willans engine by compressing air in an external air-compressor. The compression of the exhaust steam he had often found stated to be in some mysterious way a source of great economy ; but he ventured to dispute that position entirely, and to say that the force employed for the compression of the exhaust steam was a total and absolute loss as regarded economy ; all that could be said was that the working of the engine might be worse if there were no compression. A theoretically perfect engine would have no vacant spaces or clearances ; and the first cubic inch of steam that got in behind the piston would immediately raise the pressure to the full pressure in the boiler. In any actual engine however the whole of the clearance had first to be filled with steam up to the boiler pressure before this pressure could come into action behind the piston for commencing the working stroke. In every high-speed engine the amount of the compression required was easily calculated from the velocity and weight of the moving parts. When first designing high-speed engines some years ago he had held the prevalent idea that it was rather an advantage to increase the weight of the piston ; but a little experience had shown him the utter fallacy of that notion. In the particular engine described in the present paper the weight of the pistons seemed to be increased to an abnormal extent ; and in order to see what mischief this caused, it was only necessary to look at the indicator diagrams, Figs. 12 and 13, Plate 52. In Fig. 13 the compression actually raised the pressure up to 100 lbs. per square inch, which

(Mr. Arthur Rigg.)

was something like 5 tons on a 12-inch piston: that is to say, a pressure of 5 tons had to be accumulated at the end of every non-effective return stroke in the single-acting engine, and the work done in accumulating this heavy pressure was entirely thrown away. That action was not conducive to economy; and in fact how economy could possibly be reached by any high-speed engine with heavy pistons he found great difficulty in seeing. The engine described in the paper seemed to embody a popular prejudice against the slide-valve, for which he did not know the reason, because nothing could be more simple or satisfactory than the working of a slide-valve with an eccentric; and he could not understand why so much trouble should be taken in this and other engines to get rid of the slide-valve, with the result always of getting a bad indicator diagram. The reason why all the early high-speed engines were so exceedingly extravagant, and why the Corliss engine when it first came into vogue some years ago produced such a revolution in the ideas of engineers, was simply little more than the question of clearance. The old engines, which were displaced by the Corliss engine, had valves with long ports, a comparatively short stroke of the piston, and the clearances considerable. The first thing Corliss did was to design a valve which had very small clearances indeed; and the next thing he did was to double the length of the piston stroke, so that the ratio of clearance was smaller in the Corliss engine than in any other. These were not the sole causes of the economy of the Corliss engines, because there were also questions of heat and of other matters which he need not now enter upon. The Willans engine was the first example of a high-speed engine in which there was anything like a reasonable economy; the principal and most important reason was that the piston-rod was enlarged, the valve was put inside it, and the clearances were reduced almost to a minimum, without the area of the steam passages being in any way restricted. In order to get over the difficulty which thence arose of not having sufficient capacity in the passages to serve as a buffer spring for bringing the pistons to rest, it was necessary to have recourse to the outside arrangement of an air-compressing cylinder. The compression and recoil of the air was really in his own opinion

the principal reason of the great economy in the Willans engine. Another high-speed engine, the Westinghouse, had not been by any means economical until it had gone a certain distance in the direction of Mr. Willans' ideas, to the extent of using a vacuum instead of compression, and reducing the clearances, whereby he understood better results had now been obtained than prior to the adoption of the vacuum. It thus appeared that, the more the clearances were reduced, the better were the results realised. When it came to compressing the exhaust steam, as most of the high-speed engines did, it became necessary in the engine now described, as had been mentioned by the author, actually to increase the clearance, in order to avoid the loop which otherwise appeared in the indicator diagram: that was to say, the compression became higher than the boiler pressure. In order to bring the piston to rest properly, there must of course be a certain proportion of clearance in the cylinder; but the result of the enormous load of 5 tons on the 12-inch pistons of the engine now described had been that the exhaust had to be closed at about half stroke or possibly a little later, and all that compression was entirely thrown away. The only way that he had ever seen to remove all the difficulty was by the kind of engine shown in Fig. 23, Plate 55, of which there was a model on the table. If in the ordinary three-cylinder engine, instead of the engine itself being fastened down and the crank-pin turning round, the engine were left free and the crank-pin fastened and the steam turned on, the engine would itself revolve round the crank. Whatever arrangement was made in the way of clearance &c. to obtain economical results, the same economy was achieved, whether the crank-pin was turned round by the engine cylinders, or whether the crank-pin was fixed and the cylinders revolved round it. Although at first sight this might seem a change without much difference, yet the difference was great in the practical working of the engine. The three pistons, being set radially at 120° apart and attached to the rim of the fly-wheel, were in perfect balance, and never altered appreciably their radius or their angular velocity. While the three pistons were thus concentric in regard to the fly-wheel and shaft, the three cylinders were eccentric, being carried upon a different

(Mr. Arthur Rigg.)

centre, namely the fixed crank-pin; in regard to the latter they never altered their radius, and were in perfect balance. As the result of this arrangement, a little engine of the size shown, having three cylinders of 2 inches diameter and 1 inch stroke, was driven at over 2,000 revolutions a minute; and though it was not fastened down, it did not shake, for the simple reason that there was nothing out of balance to cause shaking. This arrangement accordingly got rid of the difficulty attending the momentum of the moving parts, which was the crying evil in all high-speed engines of whatever construction, so long as the piston moved backwards and forwards. It had a number of collateral advantages, particularly for hydraulic engines, because the stroke could be altered. When used for driving a dynamo, it could be governed, and with a water pressure of 700 lbs. per square inch could work the electric light just as well as any steam engine. There was a popular idea that practically hydraulic engines could not be governed; but there was really no difficulty in the matter if only it were done in the right way. Experience in working a hydraulic engine with 700 lbs. water pressure, with which it had now been running well for six years, showed that a much more severe test was thereby obtained than with steam: the principle of the engine being the same, whether it were worked with water or with steam. A revolving engine he thought was the only way of getting over the difficulty of reciprocating parts.

Mr. Henry Davey suggested that it would be convenient for understanding the economical principles of any new engine if on the indicator diagrams the clearance space were added, and the true expansion curve were thereby drawn backwards and upwards from the terminal pressure. The diagram so obtained would then show the number of expansions due to the difference between the initial pressure and the terminal pressure; and being free from compression would represent the efficiency of a perfect engine working between those pressures, that is the ratio of the mean effective pressure to the mean forward pressure. By increasing the back pressure, compression might be, as pointed out by Mr. Rigg (page 235), a great disadvantage in regard to economy. The high-speed engine described

in the paper was one in which clearance could be reduced to a minimum. There were engines in which it was difficult to reduce the clearance space to small dimensions; and in any such engines, where it was absolutely necessary to have large clearance space, compression might be an element of economy. But in an engine in which it was necessary to increase the clearance space in order to get good mechanical working, then he failed to see that compression was an element of economy. A large portion of each of the indicator diagrams exhibited was taken off by compression, whereby the average forward pressure was reduced while the average resistance or back pressure was increased, so that the mean effective pressure was reduced. In the small indicator diagram shown in Fig. 19, Plate 53, it would be seen how small a mean effective pressure was obtained as compared with the mean effective pressure of a perfect diagram having the same initial and terminal pressures.

As regarded the mechanical construction of the engine itself, it seemed to him highly undesirable that there should be such heavy weights in the pistons and in their connections with the crank-shaft, and he thought they could be dispensed with; the pistons he had no doubt could be much lightened. The construction of the packing he also thought was not quite satisfactory for passing over the steam and exhaust ports, for which he believed it would be found necessary in an engine of this kind to put in packing rings of the construction usually employed in piston-valves. The packing shown seemed to be of too rough and ready a description for this particular purpose, and he thought it would not be found to be steam-tight. The geometry of the valve motion appeared complicated, and difficult to follow without close study; it had evidently taken a great amount of thought to work it out in a satisfactory manner, and he could but admire the ingenuity that had been brought to bear on the early development of the engine, which he supposed was still in an experimental stage. The principle of having two pistons moving in opposite directions, for the purpose of reducing vibration and obtaining quick running in a satisfactory way, seemed to be an exceedingly good one. Whether this was the most practical way of carrying out the principle, he was not prepared to say; and he

(Mr. Henry Davey.)

thought that if, instead of making the piston its own valve, a separate valve was introduced to give a better steam distribution, a better engine would be produced.

Professor T. Hudson Beare was rather surprised that the paper had not given any brake results of the engine. It seemed remarkable that with an engine running at such a high speed the indicator diagrams alone had been relied upon for ascertaining the horse-power of the engine. The actual diagrams themselves showed how untrustworthy an ordinary indicator was when running at so high a speed as 800 revolutions a minute; and therefore it would have added considerably to the value of the results if the brake horse-power had been given. It might add also he thought to the interest of the indicator diagrams if an expansion curve were drawn on each for the actual amount of steam admitted into the cylinder. The total discharge steam had been measured, and the actual steam consumption per horse-power per hour had been given; and therefore it would be easy on the line of the boiler pressure to plot the latter, reduced to the consumption per revolution, and to draw the expansion curve, which would perhaps afford the means of judging a little better as to the real value of the indicator diagrams, and whereabouts some of the faults of the engine were to be found. The steam consumption was no doubt a fairly good result, but by no means remarkable. One direction for improvement had already been suggested, namely a reduction in the present amount of compression, which seemed excessive for an engine of this kind.

Mr. Bryan Donkin asked what was the percentage of clearance in proportion to the whole stroke of the pistons; it seemed to him to be remarkably small. The absence of cylinder covers was a novelty. Proper brake trials would be valuable, as Professor Beare had suggested, in order to ascertain the mechanical efficiency of the engine. It seemed to him that steam-jacketing would have some good effect; the expansion was considerable, and he should be glad to know the dryness-fraction of the steam at release. The reflecting indicator described by the author he had himself tried for slow

speeds; below 100 or 150 revolutions per minute he had found it of no use; but at 500 or 600 revolutions it seemed to work well. This indicator however gave no diagram on paper; following the line of light led also to personal errors in sketching the diagram in. The Wain indicator seemed to him to be the best; its parts were extremely light, the spring acted by torsion instead of by compression, and there were many good points about it, which led him to think it was well worth trying. The consumption of 28·2 lbs. of feed-water per I.H.P. per hour, mentioned in page 223, appeared to be when non-condensing; he should be glad to know what the result was when condensing.

Mr. C. Frewen Jenkin asked whether it was possible to arrange the mechanism of the engine so as to give less compression, without at the same time altering the point of cut-off and the point of release. With a single eccentric and an ordinary slide-valve it was not possible to get an earlier cut-off, according to Professor Unwin, than five-eighths of the stroke, without excessive compression and too early a release. In the engine described in the paper he understood that the cut-off was at about 25 per cent. of the stroke (page 219), and that the great compression was the consequence of so early a cut-off; and he should like to know whether it was possible to alter the mechanism so as to reduce the compression without also altering the cut-off to a later point in the stroke.

Mr. Archibald P. Head thought the reason why the results hitherto obtained from the reflecting indicator were not altogether accurate (page 229) was not far to seek. It seemed to him that in this indicator, in which the ordinates of the steam and exhaust curves were in proportion to the angular deflection of a beam of light, and this deflection was caused by the bulging of a disc, the resistance to bulging must increase with the pressure: so that a given increase of pressure would cause a smaller angular deflection of the beam at high pressures than at low. That would naturally give a diagram flattened at the top; and although there seemed no reason why each disc should not be calibrated, so that the pressure at

(Mr. Archibald P. Head.)

any point could be measured, still the area of the diagram would not represent the power expended, nor would it be possible to measure by a planimeter the work done. Whether there was any satisfactory way of getting over that difficulty by varying the thickness of the disc, he did not know; but it occurred to him that one way might perhaps be to project the ray of light upon a cylindrical instead of a flat sheet of sensitised paper, in such a way that at high pressures the ray should fall upon it with greater obliquity than at low pressures; and then, when the sheet of paper was flattened out, the resulting diagram might be approximately correct.

Mr. Jeremiah Head, Past-President, thought the paper presented an instance of a distinctly novel kind of engine, and one not easy to be understood at first sight. High-speed engines generally were justified on the principle that their power was in proportion to their speed: that is, with double the number of revolutions per minute, other things being equal, double the power was obtained. This was of course an incentive to make all engines go as quickly as possible; but it was not without its drawbacks, because the momentum of the moving parts increased as the square of the velocity. In the present engine an endeavour was made to get over this difficulty by dividing the stroke between two pistons, and making them move in opposite directions. The pistons, he quite agreed with previous speakers, seemed inordinately heavy; but probably it would be said that they neutralised each other by their motion in opposite directions. This principle was not altogether a new one, the late Mr. Crampton having worked a good deal in that direction. Reciprocating weights could be really balanced only by other reciprocating weights moving in an opposite direction: they could not be completely balanced by revolving weights. In the present engine the mischief of unbalanced reciprocating weights he thought was not wholly cured, because here the two weights were not absolutely opposite, the cranks themselves not being absolutely opposite, and therefore there was a resultant movement which meant vibration; and it was these vibrations, the mischievous effects of which increased according to the square of the velocity, that limited the speed of all engines in which there were

any reciprocating weights whatever. In fact it seemed to him that the only engines which could be made to go at an unlimited number of revolutions were those of the steam turbine kind, such as that of Mr. Parsons, which was said to run up to 18,000 revolutions per minute, and commonly worked at 12,000. An engine at the Chicago Exhibition, designed by Mr. Laval, the inventor of the centrifugal separator for cream, he was told had been going at 30,000 revolutions, which certainly was the quickest he had ever heard of. It must be discouraging to all designers of quick-speed reciprocating engines to know that such high speeds could be realised by other means without any sensible vibration. Moreover all quick-speed reciprocating engines seemed to wear themselves out in a comparatively short space of time. None of them were ever heard of as lasting so many years as the old beam engines and other slow-going engines had lasted, many of which nearly a century old were still at work he believed in this country. No such duration was realised in quick-running reciprocating engines, which seemed, however carefully they were made, rapidly to disintegrate themselves. The real cause he had no doubt was the steam-hammer action alluded to by Mr. Rigg (page 235), owing to which, while their power was in the main employed in producing rotation, an appreciable portion thereof was expended in pulling the engine itself to pieces. The desirability had frequently been urged of making quick-speed engines single-acting, so that the connecting-rods should always be working on the same side of the crank-pin, either pushing the crank-pin or being pushed by it, and consequently keeping always close up against it. This was no doubt a valuable idea, but he thought the plan was not wholly advantageous. The slight slogger or play of the connecting-rod working on both sides of the crank-pin in a double-acting engine was of some advantage he believed in allowing the oil to get round the crank-pin at each revolution. He had himself had experience of a large single-acting three-cylinder engine, in which the cylinders were each 24 inches diameter, and the pressure on the crank-pin was always in the same direction; and although the crank-pin was partly uncovered and working in the exhaust steam, and although there was an impermeator constantly at work supplying

(Mr. Jeremiah Head.)

oil, and there was a lubricator to pass oil down through one of the connecting-rods to the crank-pin, yet the engine entirely failed, because it was impossible to lubricate the crank-pin efficiently. It might be that the pressure per square inch on the latter was too great; but at any rate under the circumstances it could not be lubricated. The connecting-rods seemed to him to hug the crank-pin so closely as to squeeze all oil out, and prevent any more from getting in; it therefore appeared to be not always an advantage to adopt the single-acting plan. The engine now described, which he understood was still experimental, would be carried on he trusted so as to make it as perfect as possible, and to see whether there was really any advantage in the design.

Mr. William Schönheyder noticed that it was not intended at present to make this high-speed engine above 80 horse-power (page 223), which seemed rather a small power; and he feared such an engine would not be of much use commercially, whether for electric lighting or for other purposes. He should be glad to know whether there was any reason why it should not be made of larger power. An important point which seemed to him to be rather unfavourable to the engine was that, in consequence of the cranks being so nearly opposite each other, it was really almost like a single-crank engine, and required a heavy fly-wheel to regulate it; and there would presumably be considerable difficulty in starting it, especially if there was a load upon it. As to the difficulty of lubricating the bearings when the pressure was always in the same direction, the true cause he considered was simply that too little bearing surface was allowed in proportion to the pressure and to the velocity. Hence it was that, as was well known, in bearings for the fly-wheel end of a crank-shaft, for instance, where the pressure continued always downwards, a much larger surface had to be allowed, so that the pressure per square inch should not exceed about 200 lbs., otherwise heating took place. It was the same with axles for railway carriages, and in various other cases, where the pressure was always in the same direction; and practically, if sufficient surface was allowed, there was no difficulty about the lubrication. All such

bearings ran well enough, in spite of the pressure being always in the same direction, provided it did not exceed the limit just mentioned of about 200 lbs. per square inch.

Mr. Charles E. Cowper asked whether any calculation had been made of the most advantageous weight for the moving parts, in consideration of the effect that their momentum would have upon the working of the engine. For a given size engine running at a given speed, he should imagine that a certain weight of pistons would give a better result than any other; or in other words, an engine with a given weight of pistons would work better at a certain speed than at any other. The weight of the moving parts served of course to make up for the loss in the indicator diagram caused by an early cut-off, because the momentum of the pistons helped the engine through the latter part of the stroke; this seemed to him to be rather an important feature. A minor question which he wished to ask was whether the engine had been tried without the bath of lubricant. The bath he was aware was not peculiar to this engine, being used in other high-speed engines; but it appeared to him that the power absorbed in dashing the water and oil about must in a small engine be appreciable at a high speed. Some years ago he had been engaged in the experiments tried at Erith by his late father and Dr. Anderson, upon which a paper had been read at the Manchester Meeting of the British Association in 1887 (page 562), with the object of confirming or correcting Joule's mechanical equivalent of heat. A 5-H.P. engine was employed to drive a Froude's dynamometer, and the whole of the 5 H.P. was absorbed in simply churning the water and heating it from the temperature of a cold bath up to the temperature of a hot bath. That fact, having been so strongly impressed upon his mind, suggested to him that in an engine of this kind and of small power some appreciable percentage of the power might be absorbed by the dashing about of the oil and water in the bath.

Mr. William Daniel enquired about the governing properties of the engine and its steady running. In connection with its high

(Mr. William Daniel.)

speed he noticed that the driving of dynamos was mentioned (page 224), for which purpose a fairly constantly steady speed was required. Governors were also mentioned in page 226, but without being described; and he should therefore be glad to know whether any experiments had been made to show how steadily the engine ran with varying loads.

Mr. ANDERSON said that of course it was not pretended that this engine was the most economical that could be devised. It had been designed as an engine of the single-acting class, with a particularly simple motion; and the problem was to get the best possible result from it within the limits so imposed. The valve diagrams and the indicator diagrams could not be altered more than a certain small amount. The great compression for instance (page 241) was a necessary consequence of the design of the engine, and its extent could not be altered much. The cut-off too had to take place about where it was shown in the valve diagrams, and had to be made the best of, whether it was right or wrong. The heavy pistons he thought were not altogether a disadvantage (page 235), because, as rightly pointed out by Mr. Cowper (page 245), energy was stored up in the pistons during the first part of the stroke, and was given out again towards the end of the stroke, so that no power was lost thereby. Nevertheless it had been endeavoured to make the pistons as light as possible, consistently with the design of the engine. Cast-iron pistons could not be made of less than a certain thickness, which as shown in the drawings was only something like 5-16ths to 3-8ths inch for the diameter of 12 inches; the necessary strength could not be got at much less than this. The thickness being thus settled, the weight was a necessary consequence, until perhaps some modification of design was devised which would admit of a lighter pattern of piston.

There was a tight place in this engine precisely the same as there would be in an ordinary engine of the same size and proportions, working with the same steam distribution and pressure. With equal load on the centre crank of the Grafton engine and the crank of the ordinary engine, the load on the side cranks of the

former and the load on the shaft journals of the latter would also be equal, so far as they were due to steam pressure in the cylinder; it was therefore obvious that the tight place would be identical in both engines, other things being equal. With the engine standing on the top dead centre, and the steam on, there would consequently be precisely the same amount of binding in it as in the ordinary engine; and the turning moment at that instant would also be the same as in the ordinary engine, namely nothing; since there was no effective length of arm in this or any other single engine, when it was on the dead centre. The statical moment of the friction of the engine when standing on the dead centre with steam on was obviously not a fair measure of the maximum friction when the engine was running, for the reason that the co-efficient of friction of repose was greater than that of motion; and when the engine was running the effect of the inertia of the pistons was to reduce materially the load on the crank pins at the commencement of the stroke, compared with the steam load on the pistons at the same instant.

The idea that the top piston was water-jacketed (page 233) was quite a misconception; the piston head proper was protected by the diaphragm above it, enclosing an air space, into which water had no access. It was only by means of a screw plug that the oil in the ball was prevented from being thrown out at the top of the stem of the ball; it was obvious therefore that water could not lie upon the diaphragm, to say nothing of finding its way past the diaphragm into the space, when the engine was running, even supposing a supply of water was forthcoming for the purpose. It was no doubt desirable to reduce the surface of the piston exposed to the steam; and the particular form of pistons here shown had larger exposed surfaces than simple flat pistons of the same diameter would have. The total surface exposed to the steam however was no larger than the surface similarly exposed would be in an ordinary engine of the same size and proportions, with a piston-valve set to give the same distribution; for in the latter case there would be the surface of steam passages which did not exist in this engine; moreover the fluctuation of temperature of the piston surfaces was necessarily neutralized largely in this engine by reason of the high speed it was run at.

(Mr. Anderson.)

The temperature of the bath of lubricant (page 234) had not been ascertained, as there was nothing to be gained by doing so. The bath was a necessity in this engine, as it was in others of the same class; and whatever amount of heat might be contained in the bath was accounted for in the steam consumption and in the friction of 15 per cent. The engine had not been tried without the bath of lubricant (page 245).

In calculating the indicated horse-power, the distance that the pistons travelled to and from each other had been taken as the effective stroke, as explained in the paper under the head of length of stroke; and consequently any brake action such as that spoken of by Mr. Richards (page 234) was allowed for.

With regard to compression in the steam diagram (page 235), it had not been advocated in the abstract as a source of economy. There could be no immediate economy in alternately compressing and expanding a volume either of steam or of air or other elastic fluid; but as an expedient it was quite justifiable, and the loss attending it was entirely dependent upon the conditions under which it was employed. In an air-buffer cylinder, in which the air was alternately compressed from and expanded down to the same pressure, the loss theoretically was nothing. If however the compressed cushion were allowed to escape freely into the atmosphere, the whole of the energy stored therein would for all practical purposes be entirely lost. To recover all the energy of the compressed cushion of steam in an engine, it was therefore necessary that the compression and expansion should be in inverse ratios; and to lose all the energy of the compression, it was only necessary to allow the steam so compressed to escape from the cylinder without expanding therein. It was therefore obvious that anything between these two extremes meant recovery, in some degree, of the energy of the cushion; and the amount so recovered was indicated by that portion of the area contained by the compression diagram above a horizontal line drawn through the final pressure of the expanding steam at release; while the area of the remaining or bottom portion of the compression diagram, contained between this line and the line of back pressure, represented the loss. The conclusion was

therefore evident that the energy of the pistons might be accumulated by an exhaust-steam cushion, with but little sacrifice of economy in an engine expanding well down to the back-pressure line. Incidentally however there was a positive advantage in the steam cushion, seeing that it was obtained by early closing of the exhaust; and consequently the period during which the cylinder was open to the cooling effect of exhausting was much reduced. As to a popular prejudice against slide-valves (page 236), the fact that the valve in this engine was a piston-valve practically entailing no waste space, while at the same time it was also a power-developing piston, was alone ample justification of its adoption.

For the packing of the pistons (page 239), no doubt a more perfect plan could be used; but it would make the pistons still heavier, and would take away from the simplicity of the engine, which was one of its main features. The Mather and Platt packing had been tried in one instance for the broad ring in the top piston which worked over the steam port; that added of course considerably to the weight, because provision had to be made for getting it into the piston, the thickness of which was thereby increased; but no doubt it was a better job.

As regarded the mechanical efficiency (page 240), some brake tests had been made; but as he had not been altogether satisfied with the indicator diagrams, it had been thought wiser not to include this matter in the paper; all that could be said at present was that, so far as could be judged, the mechanical efficiency was much the same as usual in high-speed engines, the brake horse-power being about 85 per cent. of the indicated horse-power. The experiments had varied from 83 per cent. upwards. When the engine was as perfect as it could be got, a proper series of experiments would be made.

The engine could be steam-jacketed (page 240) without much trouble, as mentioned in page 224, because the cylinders themselves were already liners pushed in, and it would be easy to form a jacket with these.

As to the calibration of the Perry indicator (page 233), there was no difficulty in effecting this by placing an ordinary indicator beside it on a T pipe, and admitting steam of various pressures

(Mr. Anderson.)

simultaneously into both. In this manner the spot of light would take up various positions on the screen, corresponding with positions of the ordinary indicator pointer, the value of which latter would of course be known. Or it might be done in a similar manner with a pressure gauge, only the indicator was probably more trustworthy. The ingenious way suggested by Mr. A. P. Head (page 242) for making a correction for the uneven scale of pressure would doubtless be worth trying; only it would be necessary for the scale to vary regularly. It was true that at low speeds (page 241) all that could be seen was only a spot of light moving over the paper; but at about 200 revolutions per minute it began to show a continuous line. At the speed at which this engine ran the diagram was quite continuous, and remained so steady the whole time that it could be traced with a pencil or photographed. The diagrams shown in Figs. 17 to 19, Plate 53, were from photographs.

The steam consumption given in the paper, 28·2 lbs. of feed-water per I.H.P. per hour, was the consumption when the engine was working non-condensing (page 241). A quantitative experiment had not yet been tried when condensing.

On reference to the valve diagrams, Figs. 8, 9, and 10, Plates 49 and 50, it would be seen that the points of cut-off and compression did not depend upon each other (page 241), but that any alteration in the point of compression affected the point of release, and a later compression meant an earlier release. The release was already early enough, and this fixed the compression. In a similar way the points of admission and cut-off were interdependent.

As pointed out in the paper (page 225) perfect balancing was not possible in this engine, and the reason assigned by Mr. Head (page 242) was the proper one; but the unbalanced moments were not large, and the engine could practically be run at a very high speed. In reply to Mr. Cowper's enquiry (page 245), the inertia diagram had been made out for the engine, and the speed was limited to that which would cause no reversal of stress on the crank-pins, so as to avoid making any noise.

The instance given by Mr. Head of difficulty in the lubrication of a single-acting engine (page 244) was curious; and it would be interesting to know the pressure on the bearings.

In regard to the size of the engine (page 244), it had been mentioned in the paper as 80 horse-power because he thought that, when engines were wanted of more than this power, the users would hardly be content with a simple engine, but would require a compound; and it seemed to him that there was not likely to be any commercial value in an engine of this kind if of larger power.

No difficulty had ever been experienced in starting (page 244). There had been an idea beforehand that there might be some difficulty, but it had never proved to be so; the engine started quite easily.

No special experiments had been tried as to governing (page 246). There was no reason he thought to suppose that this engine would not govern as well as any other.

The President said the author had dealt not only with the construction of this particular high-speed engine, but also with sundry points concerning valve diagrams and the use of indicators at high speeds, which were themselves of great interest. The discussion, he was afraid, had judiciously shirked some of the most difficult of these points, especially those connected with the valve diagrams shown in Figs. 6 to 10, Plates 48 to 50. These however he had no doubt would form material for careful study for some time to come. On the question of high versus low speeds, and especially of lubrication at high speeds, he had listened with interest to the views of Mr. Head (page 243), and should much have liked to express his own; but it would be hardly in order to go into any general discussion of such a question. The subject he hoped might be brought before the members formally at some time by a special paper, and be thoroughly discussed. Meanwhile he was sure the members would all join him in a hearty vote of thanks to Mr. Anderson for his paper, and especially for the thorough and complete manner in which he had worked out the complex details of his subject for putting it before them.

DESCRIPTION OF A FLUID-PRESSURE REVERSING GEAR FOR LOCOMOTIVE ENGINES.

By Mr. DAVID JOY, of London.

Single-Eccentric Valve-Gear.—Ever since his former paper to this Institution in 1880 (Proceedings page 418) describing the radial valve-gear which he was then introducing, the writer has entertained the idea of a yet simpler and more direct form of Reversing and Expansion Valve-Gear than either the radial itself or any other plan hitherto in use. Notwithstanding the success achieved with the radial gear, the difficulties encountered in its introduction convinced him that a better plan was required, and enabled him to see the direction in which to work. From the outset the idea kept prominently in view was that only a single set of pieces of mechanism should be employed, instead of a duplicate set, for actuating the valve from the crank axle, and also for reversing from forward to backward gear; and further, that reversal should be accomplished by the change of position of the gear, as in the radial gear, and not by the addition, as in the link gear, of other and distinct parts for backward running. Accordingly the single eccentric with shifting position on the crank axle, as in Dodds' wedge-motion, naturally recommended itself for adoption: while the difficulties and complication involved in any attempt to effect the shifting by mechanical connections through levers, links, screws, or friction gear, which would have been fatal to practical success, led the writer to throw all such expedients aside, and to have recourse to the employment of fluid pressure, by means of oil or other fluid conveyed through the centre of the axle itself for shifting the position of the eccentric. The purpose of the present paper is to describe the construction and working of the Fluid-Pressure Reversing Gear designed in conformity with the foregoing ideas, and already in practical use for locomotive running.

The general principle of the fluid-pressure reversing gear will be readily understood from a comparison of the skeleton diagrams, Figs. 14 and 15, Plate 62, showing the main centre lines of the ordinary link gear and of the fluid-pressure gear. In the link gear, Fig. 14, with its two eccentrics F and B for forward and backward going respectively, the motion of either is transmitted to the valve spindle V through the motion link L coupling the outer ends of the two eccentric rods. In the fluid-pressure gear, Fig. 15, the same result is obtained more correctly and with less than half the number of parts, by employing only a single eccentric, and shifting it transversely across the axle from side to side for forward or backward gear. For this purpose the axle is squared where the eccentric is mounted upon it; and an oblong slot through the eccentric allows it to be slid across from side to side of the axle. In each end of the slot is formed a small cylinder, which works over a corresponding ram fixed on opposite faces of the square on the axle. It only remains to force oil or other fluid under pressure into either end of the axle, and thence into one or other of the two small cylinders, according as it is required to move the eccentric into either position for forward or backward gear, or to hold it between these extremes for any point of expansion or for mid gear. The oil is made to pass into either end of the axle by a small cylinder, placed on the footplate of the engine, and fitted with a piston which is moved either by a handwheel and screw or by steam, or by both.

The arrangement is shown in Plates 56 to 62, as adapted for locomotives.

Fig. 6, Plate 60, is a cross section through the crank axle and the square block mounted upon it, on which the eccentric slides. Fig. 7 is a plan showing the square block and the two pairs of rams upon it, with the near halves of the eccentrics removed. Fig. 8 is a longitudinal section through the centre line of the axle. Figs. 11 and 12, Plate 61, are longitudinal and cross sections through the axle and block, the former view being taken diagonally through the corners of the block, in order to show the passages for the oil from either end of the axle into the respective cylinders for moving

the eccentrics into forward or backward gear. This is also shown by the small model exhibited.

Fig. 1, Plate 58, is a side view of a locomotive, showing specially the reversing cylinder C on the footplate, from which the oil is forced into either end of the axle through the pipes PP. Fig. 2 is a back view and Fig. 3 a plan of this part.

In Plate 56 is shown a photograph of the "Sussex" locomotive, a passenger engine on the London Brighton and South Coast Railway, which has been fitted with this reversing gear. Also in Plate 57 a photograph of the driving wheels stripped, showing one set of valve gear complete, and the eccentric on the other side removed to show the rams and cylinders.

Construction of Gear.—The square block B, Figs. 6 and 7, Plate 60, mounted on the crank axle, is parted diagonally and bolted together at the corners, its four faces being planed to the square. On two opposite faces are cast the rams R working in the small cylinders cast in the two halves of the eccentric E, which are bolted together on the centre line as usual. The internal faces of the slot in the eccentric are planed to slide upon the parallel faces of the block The slot is long enough to allow the eccentric to slide across the centre line of the axle into the extreme positions of forward and backward gear; and the block is so set on the axle as to give this motion at right angles across the line of the crank (when the piston is at either extremity of its stroke) and outside the centre line of the axle. If however the centre line of the valve spindle is not parallel with the centre line of the piston rod when both are projected upon the same vertical plane, then the block must be slightly turned round upon the axle, until at either extremity of the piston stroke the slot is at right angles to the centre line of the valve spindle, instead of to that of the crank.

Oil.—The oil enters at each end of the axle, Plates 59 to 61, and passes along the central hole to nearly the middle of the length, whence it is led radially into the two longitudinal channels I and J formed in the corners of the block B. From one of these channels I it passes to the two rams for giving forward gear, and from the other

channel J to the other two opposite rams for giving backward motion. The oil forced from the reversing cylinder C through one of the pipes P to either pair of rams displaces that from the opposite pair, and drives it back through the other pipe P into the opposite end of the reversing cylinder C. It thus acts as a continuous non-elastic medium, transmitting exactly the motion of the piston in the stationary reversing cylinder C on the footplate, through the pipes PP, to the rams actuating the eccentrics; and the eccentrics are thereby shifted and held in any position, without being affected in the slightest by the revolution of the axle, and quite independently thereof. The fluid-pressure reversing gear thus serves all the purposes of the levers, links &c., which have hitherto been used in other reversing gears, but is devoid of parts subject to wear and tear and requiring repair. In place of adding the square block B, as is done for existing engines, for new work the part of the axle carrying the eccentrics may itself be squared, thereby saving the cost of fitting the block.

As an additional security for the stability of the eccentrics in any position, and in order to keep them both relatively in the same grade of gear, they are locked together in the manner shown dotted in Fig. 10, Plate 61, by means of a pin and block K, fixed in the inner face of one eccentric, and sliding diagonally in a slot S formed at an angle of 45° in the inner face of the other eccentric. Thus when one eccentric is falling vertically from full forward to full backward gear, the other is simultaneously sliding horizontally through precisely the same extent of shifting; and for all intermediate positions the two eccentrics are maintained both of them in the same grade. As each is in its best position to sustain the strain of driving its own valve at the time when the other is in its worst position, they mutually assist in keeping each other in place, and so to a considerable extent relieve the pressure upon the oil.

The oil pipes PP enter the ends of the axle through stuffing-boxes, as shown in Fig. 5, Plate 59; the gland is screwed into the axle, and is prevented from unscrewing itself during the revolution of the axle by a squared head and bridle D. A collar C screwed and pinned on the inner extremity of the pipe prevents it from being

forced out of the gland by the pressure of the oil, which has varied from 60 to 100 lbs. per square inch.

Reversing Cylinder.—The reversing cylinder, filled with oil, is shown in Fig. 13, Plate 62. It is placed at C, Figs. 1 to 3, Plate 58, on the engine footplate; and from its opposite ends the pipes PP convey the oil to the opposite ends of the crank axle. The piston in the cylinder is moved in either direction by a screw on the piston-rod, which works in a nut forming the boss of the handwheel H; or else, as shown in Fig. 13, the piston-rod is itself the nut, in which works a screw rotated by the handwheel. Any movement of the handwheel thus produces a corresponding movement of the eccentrics. The movement of the handwheel is assisted by a small air cylinder A added in front of the oil cylinder, Plate 58; by admitting compressed air from the Westinghouse brake reservoir into either end of the air cylinder through a four-way cock, the reversing is rendered so easy that it can be done with only a couple of fingers on the handwheel, even when the engine is running with full steam on.

Principles.—From the foregoing description of the arrangement it will be seen that the two leading ideas in this plan of reversing are:—firstly, that the same mechanism is employed for forward and backward running, reversal and expansion being effected simply by the change of position of the mechanism; and secondly, that this change of position is effected, not by any mechanical combination—which would necessarily be complicated, because the adjusting power must be stationary while the adjusted mechanism is in rapid motion—but by fluid pressure, of which the efficiency is independent of and unaffected by variety of movement between the adjusting and the adjusted mechanism.

Advantages. — The advantages attending this plan may be enumerated in the following order.

First, simplicity and largely reduced number of parts. Hence follows reduced liability to failure, because with fewer parts there are fewer to break down, and the parts retained may be made

stronger; the fewer joints to be looked after and lubricated may also be better attended to. If any part of the fluid-pressure gear should fail, the only result is that the eccentrics gradually slip into full gear for whichever direction the engine may be running in at the time. Thus the engine is still perfectly competent to bring the train home, with the only disadvantage of not being able to use expansion for the time.

Second, truer distribution of steam. The distribution is indeed almost mathematically correct, both for the front and back ends of the cylinder, and also for forward and backward gear alike. This is prominently shown by the exactly equal beat of the engine at all grades of expansion and when running in either direction.

Third, reduced cost of repairs. This reduction is a consequence not merely of the reduced number of parts, but also of the fact that the parts retained have so much larger wearing surfaces and so much smaller an amount of motion.

Fourth, considerably reduced first cost. In the construction of the gear there are no costly forgings, involving also expensive tooling. Nearly all the parts are castings, like cylinder castings, calling chiefly for boring and turning, which are not only the least costly of the operations in the tool shop, but also the least dependent on the workman for accuracy and finish. For every mechanical detail in the construction of the gear there are numerous and satisfactory precedents.

Furthermore, this gear can be adapted to every position where link gear is used, without any alteration of the engine; and for compounds it can be arranged to give varied cut-off for the high and low-pressure cylinders, in which case the two eccentrics are of course not connected with each other in any way. It is so simple in its construction that it is within the comprehension of any workman; and after it has originally been set in the workshop there is nothing left for the driver to adjust. It is therefore not liable to the objection sometimes raised against the radial gear, that the drivers know the link gear but cannot be got to understand the radial: an imputation however, which from his own experience the writer thinks not fair upon their intelligence.

Discussion.

Mr. JOY said that, since the paper had been prepared nearly six months ago, considerable advance had been made, especially in the mode of packing the rams in the eccentrics, which had been the subject of some criticism; and the fear had been expressed that, if the crank-axle got heated in running, the leather packings would be burnt and rendered useless. As a matter of fact however these leather packings had been working for months; and he had adopted them originally on account of their having been used so long for the Westinghouse compressed-air brake, and having scarcely ever been found to fail. On the table was shown a small ram and cylinder, which were practically the same as the rams and cylinders of the eccentrics; and also various kinds of packings which had been tested, including a simple ring of metal of U section, Fig. 9, Plate 60, which had been suggested by Mr. Billinton. Finally he had come to asbestos, because fire would not touch it. The testing cylinder exhibited, having been packed with asbestos, had been subjected to a hydraulic pressure of 250 lbs. per square inch, and perfect tightness had been obtained. Then it had been put on a red-hot plate in a smith's forge, in order to get as nearly as possible the conditions of a ram on a red-hot axle: although a locomotive axle never did get red-hot. After having been kept there for half an hour, it was again tested, and the asbestos packing was found to be still tight. Then the packing was taken out for examination, and was now exhibited; and it would be seen that it was as good as when put in. A model was also shown of the centre part of the crank-axle with the square block upon it, which could be pulled to pieces so as to show the channels inside, whereby the oil passed from either end of the axle to the middle of its length. The channels in the block were made by cores in casting it, not drilled out afterwards in the corners of the block. The model also showed distinctly the inclined slot, whereby the two eccentrics were kept together in exactly their correct positions relatively to each other, so that each assisted the other by means of the fluid pressure in their

two rams. The fluid need not be all oil, or any one fluid in particular; a mixture of water and oil answered equally well, to the extent of even ten parts of water to only one of oil. Drawings were also exhibited, Figs. 16 to 19, Plates 63 and 64, representing the marine engines of the "Apollo" type of cruiser in the royal navy. These engines were well known to have done remarkably good work; in every case they had gone considerably beyond their contract power, and there had been practically no breakdowns. They had therefore been taken as a good type upon which to illustrate the application of the fluid-pressure reversing gear to marine engines generally. Plate 63 represented the existing arrangement of link gear; Plate 64 represented the same engines with the fluid-pressure gear, and the simplicity of its application was seen at a glance. By means of the full-size working model exhibited of the locomotive gear, the effect was exemplified of any accidental failure of the fluid pressure: on turning the axle round by hand, as it would revolve in working, it was seen that, if the fluid pressure failed, the eccentrics would simply drop quietly into full forward or backward gear, according to the direction of running at the time, and the engine would still be in a position to go along. In this respect the action of the fluid-pressure gear was so far similar to that of the old hand reversing gear, where the eccentric had a snug or toggle fast on it, allowing it to slip part way round the axle in either direction, backward or forward, till it engaged with a similar snug on the axle; and the eccentric being driven by this snug had always the tendency to slip towards it, that is to fall into full gear. The engine "Sussex" shown in Plate 56 had now been running over twelve months, and every facility had been given by the Brighton Railway Company through their locomotive superintendent, Mr. Billinton, for enabling any experiments to be tried with the gear, even to the extent of a breakdown; and on one occasion a breakdown had been arranged, which took place while the engine was 35 miles away from home with a train; but the passengers knew nothing about it. The engine brought the train home, and there was no difference beyond burning a little more coal, on account of having to run the whole of that distance in full gear without

(Mr. Joy.)
expansion. By the kindness of Mr. Billinton the engine had been on view in steam during the day at the Victoria Station of the London Brighton and South Coast Railway.

Mr. Lewis Richards asked if the lead would not vary as the throw of the eccentric was increased. As the centre of the eccentric travelled here in a straight line when shifting from one extreme position to the other, the length of its throw must diminish from full gear to mid gear, which with the obliquity of the eccentric rod seemed to him to mean some variation of the lead in mid gear.

Mr. Joy replied it was quite true that the lead did vary towards mid gear; but the variation was so minute that in the full-size model exhibited it was scarcely visible, as was at once verified by placing the crank on either the front or the back centre, and shifting the eccentric across from one extreme of full gear to the other; it was seen that the valve remained practically motionless. In fact with 63 inches length of eccentric rod, as here shown, and $1\frac{7}{8}$ inch throw of the eccentric, the actual amount of the variation was only $0 \cdot 02$ inch, which was almost inappreciable. The result was therefore practically an even lead for all grades of expansion.

Mr. T. Hurry Riches, Member of Council, noticed that the drawings showed the application of the plan to engines having outside axle-boxes and single drivers; and so long as there were no coupling rods to contend with and no outside cranks, there seemed no difficulty in getting the fluid pressure into the driving axle in the manner described in the paper. But it did not seem quite clear how it would be got in where there were outside cylinders and where there were coupling rods. Again in attaching the square block upon the axle there appeared to be the difficulty of efficient packing for ensuring security from leakage of the oil where it passed out of the hole in the axle into the hole in the block. After the eccentric had run for some time, he feared the bearing surface of the block must inevitably get somewhat worn; and it appeared to him that there would be a difficulty in maintaining for any length of time an

absolute security against waste. If any leakage did occur, he gathered from the description already given that the slack so occasioned inside the fluid passages and rams would allow the eccentric gradually to fall into full gear, and thereby some fuel would be wasted. Economy of fuel was of such importance to all railways, that they naturally looked at these matters with a rather critical eye; and before launching out into any new contrivance which would have to be applied largely in order to obtain its full advantage, every point had to be carefully considered. As to the general idea of the plan now described, it was certainly a great advance in simplicity; and it seemed to him a most desirable improvement, if it could be accomplished so satisfactorily as represented by the author.

Mr. George Cawley noticed that in the drawing of the reversing cylinder, Fig. 13, Plate 62, there was only one handwheel for working the two eccentrics. For pushing the eccentrics over into full gear from one extreme to the other he could understand that a single handwheel would suffice to actuate the fluid through the whole extent of the stroke of the rams. But supposing that the friction on one eccentric was a little greater than on the other, was there any possibility that in an intermediate position of gear one eccentric might have a greater cut-off than the other? It seemed to him that the correct action of the gear depended on the exact balancing of the friction of the two eccentrics; and that if one of them had a slightly easier travel than the other, then, although the fluid pressure would still in some way be balanced between them, yet they would not both have the same cut-off.

Mr. Henry Davey recollected that the beautiful oscillating engines of the late Mr. Penn's design, which used to be seen in the steamers on the Thames, had the shifting eccentric and the old gab or gap device by which the eccentric-rod end was disengaged from the valve-rod, leaving the valve to be moved by hand, so that it could be brought over for forward or backward running while the shaft was turned round to engage again with the eccentric in the reversed

(Mr. Henry Davey.)
position. If it ever happened in that arrangement that the eccentric was not quite free on the shaft, but was binding upon it, the eccentric might be held in a false position; but immediately the friction disappeared, the obvious tendency was always to run into its true position.

In the application of the fluid-pressure reversing gear, it had been explained clearly what would happen if the pressure leaked off while the locomotive was in motion; but what would be the result of such an accident if it occurred whilst the engine was standing at a station, and if it was then required to be reversed for running in the opposite direction? How was the gear going to be started from a state of rest?

With respect to the adoption of a fluid consisting of ten parts of water and one of oil, he had himself had about twenty years' experience with fluid valve-gears, and having commenced with oil had then gone on to oil and water mixed. For many years however he had now used nothing but distilled water, and had avoided putting the slightest drop of oil into the gear; and he had found this plan to answer best. With regard to the packing, in the fluid gears with which he had had experience the fluid was used as a brake, and the distilled water naturally got hot, because it had to absorb mechanical power. The packing which he used was simply a gun-metal packing-ring, which was very accurately fitted. Some of the gears had been working for twenty years, and he believed no new packing had been put into them. It was necessary however that the water should be absolutely clean and free from grit. The great difficulty experienced at first was that the sand had not been washed out from the ports of the cylinders before the gear was put to work. Asbestos for packing he had never tried; but he was afraid, if it were attempted to be used with water in the fluid-pressure reversing gear, it would be attended with a difficulty. Asbestos would stand extreme heat; but it would not stand water. So long as it could be kept dry, the metal in contact with it might be made red-hot without destroying the asbestos; but if it were exposed to water or oil he was afraid it would be found that it would be quickly destroyed. On this account he thought Mr. Joy would eventually come to a metallic packing.

He asked whether any difficulty had been found from the expansion of the fluid. It was in a confined space, and there did not seem to be any safety-valve anywhere. If the fluid happened to be cold when the gear was started in the morning, and got warm during the day, there would be some amount of expansion. What provision was there for giving room for the increased volume? The greatest fear he had for the gear was with regard to leakage; but he thought this was not an insurmountable obstacle, and he had no doubt it would be got over and that no practical difficulty would be experienced. If there was any considerable amount of leakage, it seemed to him that it would rather upset the arrangement. The little oil-cup which he noticed was placed on the fluid-pressure cylinder, and connected therewith by a two-way cock, he supposed was for the purpose of admitting a little more oil, should there be a vacant space left by leakage. That was a device which he had constantly used himself in his own gears. Using water as he did instead of oil, he had sometimes connected a small pipe from the steam-pipe to each end of the water cylinder, having a non-return valve on the pipe, so that the condensation of steam from the steam-pipe automatically supplied the loss from leakage.

Mr. J. Lyons Sampson asked what provision was made to prevent the fluid from freezing in the pipes. If the fluid were frozen solid, it would be rather awkward to start with a gear of this kind. The exposed position and small size of the pipes would render them specially liable to this defect in frosty weather.

Mr. William Schönheyder thought the gear seemed to have most of the advantages which were ascribed to it in the paper. It was certainly simple, and must be cheap to make; and there was practically no wear on it. The difficulty mentioned (page 260) as to the slackness of the eccentric on the square block he thought would hardly arise, especially if the gear were applied to a new engine, in which the square would be forged on the axle, and the rams also would be forged on the axle. By that means the pressure for driving the eccentric round was exerted by surfaces which were forged solid

(Mr. William Schönheyder.)
on the axle, and were at a considerable distance from the centre of it, and he thought the wear would therefore be exceedingly small. At the same time there seemed to him to be also some considerable disadvantages connected with the fluid-pressure gear. How was the driver on the footplate to know the position of the eccentrics? From the position of the piston in the reversing cylinder it did not follow that the eccentrics were in a corresponding position, because if there was leakage in either of the passages the eccentrics might have shifted their position without the driver knowing it. Unless there was some kind of tell-tale, it seemed impossible to know what position the gear was in. Moreover if the leakage would cause the eccentrics to go into full gear, it seemed to him that they must be always going into full gear, because it appeared unlikely that any arrangement of this kind would last tight for any length of time; if there was the slightest leakage, it was only a matter of time for the eccentrics to go into full gear. In the application of the plan to marine engines, it seemed simple enough to provide pipe connections to a couple of eccentrics, as in locomotives; but he did not understand how three eccentrics were provided for, unless instead of only one hole two holes were drilled in the shaft, because in a triple engine the passage drilled into the forward end of the shaft and that drilled into the after end must cross each other somewhere, in order to get to the third eccentric situated midway in the length of the shaft. If the gear was to be the success that he hoped it would be, he would suggest that, instead of using two pairs of rams and cylinders for reversing two eccentrics, one pair alone might be made to do for both eccentrics: instead of a pair of rams and cylinders taking hold of each eccentric, one pair alone might be made to take hold of the pin connecting the two eccentrics by the slanting slot shown in Fig. 10, Plate 61. It seemed to him that it could be done in that way, with the great advantage that there would be only one pair of rams and cylinders instead of two. Moreover in that way the leathers or other packing could be got at for tightening or renewing, without taking the eccentrics to pieces. It was highly objectionable he considered to have to take eccentrics to pieces after they had once been fitted together; they might be got right in

putting them together again, or more probably they might be a little wrong, so that they would heat when set to work again. In most inside-cylinder locomotives there was room for four eccentrics in the middle of the axle between the two crank-throws. If therefore only two eccentrics were used, it would be quite possible he thought for the one pair of rams and cylinders to be put in between the two eccentrics. He asked what kind of packing was employed at either end of the axle: whether it was an ordinary stuffing-box packing set up by a screw, in which case he feared it would wear and get leaky; or whether it was a leather, of some shape which would keep itself tight. In the application to marine engines it seemed to him that in this particular there would be much more difficulty in arranging the gear than for a locomotive, because the larger stuffing-box suitable for the size of the screw-shaft was more difficult to keep tight than the smaller stuffing-box just large enough for the pressure pipe in a locomotive.

Mr. Frederick Edwards thought that in the application of the fluid-pressure reversing gear to marine engines it would be objectionable not to have the means of independent adjustment for the several cylinders. In most of his own engines the valve gear could be adjusted separately for each cylinder, which he thought was very necessary. In the new gear he did not understand how it would be possible to modify the working of the engine by shifting one eccentric alone without the others. Then again the locomotive crank-axles were all solid, whereas all the marine crank-shafts that he used were built up. If these were to be bored for making all the oil passages shown in the drawings of the locomotive axle, he feared there would be a good deal of leakage of oil through the numerous joints of a built-up shaft during the working of the engine. In this matter he had had rather a curious experience with one shaft. Many marine engineers believed, as he himself had done years ago, that, if by applying the turning gear the oil could be wrung out of any joint or flaw in the shaft, it stood to reason that the shaft was not sound. A question having arisen about the soundness of a shaft in an old steamer, he had tested it with the

(Mr. Frederick Edwards.)
turning gear, and had found he could wring the oil out of so many of the joints, that he decided to try a comparatively new shaft. Having a new steamer handy, which had been only one voyage, he tried the shaft in it, and found that the oil could in some parts be wrung out; it was true that not much came out, but there was enough to prove this could be done with a shaft which, so far as it was possible to tell, was perfectly sound and good. The stress put on the shaft with the turning gear during this test would be far less than the ordinary working load. When he first found oil could be wrung out of the comparatively new shaft, he thought it might give trouble; but in fact it never gave any trouble at all. In view however of the possibility of thus wringing oil out of the present crank-shafts of marine engines, it seemed to him that, if all the oil passages shown in the drawings came to be drilled in a built-up shaft, there would be leakage of oil, and consequent trouble. In regard also to taking up the wear of the eccentric, he certainly was afraid that would be a trouble, which he should not at all like to encounter. Any trouble of that sort in a steamer abroad on a long voyage would be very objectionable. Moreover he did not understand exactly how the fluid pressure was made to act upon the eccentric of the middle cylinder; the first and third eccentrics being on the ends of the crank-shaft corresponded with the two eccentrics shown on the locomotive axle, and would receive the pressure in the same way as in the locomotive. But how was the pressure to be conveyed to and from the middle eccentric on the crank-shaft of a marine engine, when the oil on each side of it, that is between itself and the other eccentrics, had leaked out?

Mr. Sidney Stone understood from the description given in the paper that the driving of the eccentrics was done by the square block on the axle. That being so, and supposing the length of each side of the square was 8 inches, the area of driving surface on each side of the axle would be not more than 4 inches, or together 8 inches, multiplied by the thickness or breadth of the eccentric where it bore against the block. On the Brighton engines the late Mr. Stroudley had introduced an eccentric which had across its outer face a pair

of projecting lips fitting on the web of the crank, and extending along it for about five inches length, as far as the radius of the eccentric itself would admit. The same plan had also been used largely on the Great Eastern engines, but had now for some time been discontinued, because it was found that before the engines had been running long there was a considerable amount of play between the web and the lips. It occurred to him therefore that, if there was so much play with eccentrics fixed on in that way with the lip bearing on the crank web, and screwed up tightly one to the other with square-headed bolts and the holes filled in with white metal, some little trouble would probably be experienced in the same direction with the fluid-pressure gear, in which the eccentric did not fit tightly but must be sufficiently free to slide for reversing. To make up for the oil passage drilled along the crank web, he supposed the web would be strengthened up with more metal in it; because the general experience he believed was that the webs of locomotive cranks gave the most trouble. In the case of an axle having the square block forged solid upon it in the first instance, he asked how the author managed with regard to the passages I and J in the corners of the square block shown in Figs. 11 and 12, Plate 61.

Mr. Charles E. Cowper mentioned that asbestos was successfully used for the packing of steam cocks, such as blow-off cocks for boilers, which were of course subjected to the heat of the water in the boilers. Asbestos was also extensively used dry as packing for spindles of large valves employed for controlling blast heated to the temperature of red-hot iron.

Mr. G. S. Young asked how much the diameter of the eccentric was increased for the application of the fluid-pressure gear. It appeared to him that in quick-running engines especially, in order to reduce the friction, the smaller the eccentric could be kept, the better gear it made. With the shifting eccentric now described it seemed to him that the diameter was materially increased.

Mr. Basil H. Joy mentioned that in the first form of the gear there were no rams in the eccentric, and the oil acted direct on the square block, the eccentric being enclosed between discs, whereby the slot in the eccentric was made to perform the function of the cylinder, and the block that of the ram. There was consequently a large circular surface to be kept oil-tight over the face of each disc; and though it was made pretty nearly tight, it was not quite satisfactory. Now however in the present form shown in the drawings it was all right. As to the packing remaining tight for a length of time, he had recently visited the Tower Bridge works, where the rams of the hydraulic lifts, packed with ordinary hemp packing, were working at 800 lbs. pressure per square inch, and they were perfectly water-tight; the rams were quite dry as they came out of the packing. In the eccentrics it must be borne in mind that the rams were not continuously working, as in a hydraulic engine or a lift; but the eccentric was moved over only when the engine was reversed or linked up. The motion was only through a certain short distance of three or four inches, and it was not continuous.

The even lead in all grades of expansion was a marked feature of the gear. In running both with expresses and with slow trains, the beat of the engine was perfectly regular, thereby showing how much better the single-eccentric gear was than the link, with which the beat so often seemed to follow a sort of three-legged rhythm.

In the reversing cylinder on the footplate, shown in Fig. 13, Plate 62, there was a margin of 50 per cent. more oil than was contained in the whole of the pipes, passages, and rams: so that a large amount would have to leak out before anything detrimental could happen.

The asbestos packings which had been exposed experimentally both to water and to heat had all proved perfectly tight both before and after exposure to heat, when tried by means of the small testing machine shown; the packings themselves were also exhibited for examination of their condition after having been so tested. The simple form of packing suggested by Mr. Billinton, consisting of a brass ring of U section, Fig. 9, Plate 60, was made with a very fine edge, which pressed against the ram, and was held up tight

against it by the fluid pressure. It could be made absolutely tight; but it was so delicate that, as soon as it was taken out for repair, the fine edge, which had to be practically like a razor, was difficult to preserve; and of course as soon as ever there was a little burr on the edge the whole efficiency of the ring was done away with.

In regard to independent adjustment of the reversing gear for the several cylinders of a marine engine (page 265), the drawing shown in Plate 63 had been copied from a published drawing of an existing engine built for the government, fitted with the usual link reversing gear, and devoid of any independent adjustment for the different cylinders. The omission therefore of independent adjustment had nothing to do with the fluid-pressure reversing gear; but its introduction in both cases would tell, as far as simplicity was concerned, very much in favour of the fluid-pressure gear.

Mr. Joy explained that in locomotives having outside cylinders or coupling rods (page 260) the fluid pressure was got into the driving axle by adding an outside overhanging crank or fly-crank, as was so commonly done in fast-running agricultural engines for the purpose of lubricating; then the fluid was got into the axle through the fly-crank just in the same way that it was led through the main cranks shown in the drawings.

In order to prevent leakage between the axle and the square block bolted upon it (page 261), a leather packing ring was placed round the orifice of each of the two holes in the axle through which the fluid passed into the block. Then when the block was placed on the axle and bolted up tight, the leather packings made a joint that would carry any pressure desired; and at these joints there had never been the slightest trouble with the engine. It had been running now more than twelve months, and had done all manner of work, from the fastest expresses to trains stopping every two miles, and shunting. Again, supposing a joint did leak, it was only water or oil that leaked; and the leakage could be made up to any extent from the reversing cylinder, which, small as it was, contained enough fluid to enable the engine to continue running through a long journey, leaking all the time, yet still with margin enough to go on.

(Mr. Joy.)
Even if the margin were exhausted, as had once been the case with a bad leather, with which the engine had been allowed to go on for the sake of seeing what the result would be, the reversing cylinder could be replenished by pouring in water while the engine was running, just as the steam cylinders could be lubricated when the engine was running downhill. The reversing cylinder sucked in the oil or water, and the engine continued running just as if there had been no leakage. Although there was only one reversing cylinder for shifting the two eccentrics (page 261), yet through the pipes from each end of the cylinder and through the passages in the axle the reversing handwheel acted alike on both eccentrics; and meanwhile also they were coupled together by the inclined slot and block, which kept them in their correct positions relatively to each other. One eccentric could not move the other; but the two went together, and were held at the same point of cut-off by means of the inclined slot. The result was that the beat of the engine was so perfectly regular that the revolutions could not be counted by the beat at all.

If while there was a bad leakage from the reversing gear the engine were stopped at a station (page 262), it would start and go on again in the same direction without any trouble, because the position of the gear was not altered in stopping, and wherever the eccentrics were when it stopped, they were left in the right position ready to go on again in the same direction. Supposing however it were wanted to reverse for shunting, or in order to take a vehicle on or off, then if the fluid had all leaked away the engine could be backed by pinching the driving wheels round through a quarter of a turn back, which was enough to slip the eccentrics back. But if an equally serious accident happened with the link gear, the engine could neither go back nor forward, but would have to be taken off the train and another engine supplied. With the fluid gear however it could still go either backwards or forwards. If the engine was attached to too heavy a train for pinching back through a quarter of a turn, it was only necessary to detach it and run a turn forward, and then pinch back a turn; the eccentrics would then be in the right position for backing.

The actual area of driving surface (page 266) for the eccentric of $6\frac{1}{2}$ inches breadth on a locomotive crank-axle with block 8 or 9 inches square was altogether from 52 to 58 square inches. Where the block was forged solid upon the axle, the oil passages in the corners of the block would be drilled through the corners of the crank webs. Fracture never took place in the web in the neighbourhood where the oil passage was drilled, because the hole was in the middle of the substance of the web, where it was under no strain.

Owing to Mr. Davey's long experience in the working of hydraulic machinery, his information with regard to the use of distilled water was of much value, and he would try it for the fluid-reversing gear. If also he should come ultimately to metallic packing for the rams in the eccentrics, he should himself like it, because nothing he believed was so simple and so scientific as the brass packing ring designed by Mr. Billinton, Fig. 9, Plate 60. With regard to the asbestos packing not standing water (page 262), in the experiment he had made it had stood half an hour with water, and with a red-hot plate of iron under it; and in blow-off cocks, in which it was largely used to form the lining of the body of the cock, it was constantly subject to the pressure and temperature of the water in the boiler, and there it stood perfectly. Of course an engine would stop long enough before its driving axle got red-hot; and therefore, in trying the experiment with a red-hot plate of iron under the water press in which the packing was tested, he had done so only with the view of going to the utmost limit of the objection which had been urged against the fluid gear.

To prevent freezing (page 263), a fluid could be used which would not freeze down to 6° Fahr.; and he thought the temperature did not often fall so low in England. Even if it did, the engine would of course become warmed up sufficiently in getting up steam for starting.

As to any fear that the packings would always be leaking and the eccentrics consequently always falling into full gear (page 264), even if there was a leaky leather on the engine he believed it would not be detected by the driver while on the footplate; because even

(Mr. Joy.)
with a burst leather the leakage was so slow that the effect on the engine was extremely slight over a long journey; if the eccentrics did fall back at all from the position into which they were moved by the reversing cylinder, the change was so slight that it could not be noticed in the working of the engine. So far from the driver wanting anything like an index to show him the position of the eccentrics, all his own experience of locomotives—and in former years he had himself driven tens of thousands of miles, and had had to teach his drivers to drive—was that the drivers did not go nearly so much by the position of the reversing lever and regulator as by hearing and feeling what the engine was doing. The driver had his finger upon the handwheel of the reversing gear, and when he came to an up or down gradient he just gave the engine a little more or less steam, and never looked at the index at all, even if he had an index to go by. Meanwhile either at the end of the journey or at a station on the road he could at any time bring up the two eccentrics to their proper position, by replenishing the reversing cylinder while the engine was still running. The leakage did not really matter at all.

As had already been explained by his son (page 269), the drawing shown of a marine engine fitted with the usual link reversing gear, Plate 63, was simply a copy of the "Apollo" type of marine engines, some of which were fitted with adjusting gear so as to cut off in the various cylinders at various points, and some were not. At the present time the government were building them with that adjustment, while other builders seemed to follow no rule, but to depend upon specifications, which mostly required it. In the application of the fluid-pressure gear it could be arranged so as to cut off in any cylinder at any desired point. Thus it could be set to cut off in the high-pressure cylinder at 60 per cent., in the intermediate at 65 per cent., and in the low-pressure at 70 per cent. of the stroke, or in any other proportions, simply by adjusting the quantity of the fluid in either ram of each eccentric. Then the instant the order was given for full speed ahead or astern, there was nothing to do but to throw over the reversing lever into full gear, and all the three eccentrics went at once into full gear ahead or into

full gear astern. With the link motion on the contrary the position of the links had to be adjusted separately for each cylinder by means of a hand-screw acting upon a sliding block: so that, when it was required suddenly to go into full gear astern or full gear ahead, although the former position might be assumed at once, the latter could not be got without a re-adjustment of all three of the hand-screws. It was not so with the fluid-pressure gear; the three eccentrics all went at once into full gear with one movement of the reversing lever; and all came back to full gear in the reverse position by the reverse movement of the lever.

The middle eccentric on the crank-shaft of a marine engine (page 266) was worked consecutively from either end of the shaft according to the direction of the fluid pressure, which acted first on the eccentric nearest to the end of the shaft at which the pressure was entering; thence it passed on to the middle eccentric, and thence again to the furthest eccentric at the exhaust end of the shaft, and so back to the reversing cylinder. Practically indeed, though here described as if consecutive, the movements of all three eccentrics were simultaneous, owing to the instantaneous transmission of the fluid pressure in either direction in consequence of the oil or water being incompressible.

Mr. Frederick Edwards asked how then was the cut-off regulated for different points of the stroke in the three cylinders independently.

Mr. Joy said it was done by means of the arrangement shown in Figs. 20 to 23, Plates 65 and 66, which represented one of the eccentrics for engines of the "New York" type, like those illustrated in Plate 64. The independent adjustment was obtained of each separate eccentric, together with the means of securing full gear either way for all three eccentrics at once on reversing. Starting with all three eccentrics in full gear, the adjustment of each separately and independently was effected by producing a difference between the amounts of fluid in the two small cylinders on opposite sides of the shaft, thereby pushing the eccentric over towards mid-gear to the

(Mr. Joy.)
extent necessary for the grade of expansion desired. This operation was effected in any one of the eccentrics without disturbing either of the others, by means of a small ram-pump P, formed in the flange of the eccentric itself, with a small drilled passage I I leading from the "ahead" cylinder H on one side of the shaft to the pump, and a similar passage J J from the pump to the "astern" cylinder S on the other side; the latter passage was fitted with a non-return delivery valve. The ram of the pump was actuated by the movement of the eccentric itself, and was always pressed outwards by a spring at its base, so that its head was kept bearing against the inner surface of the ring R carried on the eccentric clasp. In its normal position, when the pump was at rest, the ring was concentric with the eccentric; but on setting it out of centre by half a turn of the small hand-wheel W, a relative movement was set up between the eccentric and the ring, and the pump was set in action, drawing fluid out of the cylinder H and passing it into the cylinder S, thereby to any desired extent varying the position of the eccentric towards mid-gear, and so altering the point of cut-off. Supposing all three eccentrics to have been thus brought into different relative positions for different points of cut-off, then at any time on passing the reversing fluid in the direction for full gear ahead it at once moved all three eccentrics in that direction; and if, owing to its previously altered position, the "ahead" cylinder H in any one eccentric did not contain sufficient fluid to pass on for completing the full movement of the next eccentric, then on arriving at the end of its stroke the ram in the cylinder H uncovered a small drilled port and passage V, through which the fluid was free to pass on to the next eccentric; and so on, for completing the movement of all three. On the instant of reversal for full gear astern, the small port V was closed by the movement of the ram H. Thus without valves or any machinery liable to derangement, the position of full reversal in either direction was secured to each eccentric, whatever their former relative positions might have been. The effect of full reversal in either direction was at once to obliterate the different grades of expansion to which the several eccentrics had previously been pumped; and when again going ahead, these grades

could quickly be restored by setting the three small pumps to work during a few revolutions. All the small channels or passages were arranged so as to be easily cleaned by a wire at any time.

There was no difficulty with the larger stuffing-box at the after end of the crank-shaft in a marine engine (page 265), because it had to do duty only during the few seconds occupied in throwing the engine over from backward to forward gear, and had no sustained work upon it. The pressure was applied at the forward end of the shaft to lift the eccentrics from full forward gear to any desired point of cut-off; and at this end the pipe was small, and might if required be double or treble packed, having successive cup-leathers one after another.

The eccentrics were a little larger in diameter (page 267) than for the link motion, but not much; but they were made much thicker or wider. Instead of only $1\frac{1}{2}$ to 2 inches width, the eccentrics were now made 3 or $3\frac{1}{2}$ inches wide, by which means the frictional load per square inch was so largely reduced on the wearing surfaces that in the course of twelve months' running of the locomotive no heating whatever had occurred, nor any appreciable wear.

Mr. Jeremiah Head, Past-President, asked whether the boiler had to be lifted up higher in the locomotive, to admit of the larger eccentrics working beneath it.

Mr. Joy replied that the increase in diameter was not so great as to necessitate raising the boiler, because no new part was so high as the crank and connecting-rod end. But even if this had been requisite, he should not object to the boiler being raised as much as was needed; for from long experience of engines with high boilers he knew that, within reasonable limits, the higher the pitch of the boiler in a locomotive, the more easily would the engine run.

The President was sure the members would desire to present a cordial vote of thanks to Mr. Joy for his paper.

MEMOIRS.

William Coulson was born at Whickham in the county of Durham on 14th April 1816. He became a mining engineer, and was connected with the winning of the following collieries:—Seaham, Silksworth, Heaton, Adelaide, Bowburn, Coxhoe, Crow Trees, Evenwood, Grange, Haswell, Thornley, Sherburn, Sherburn Hill, Castle Eden, Seaton, Waldridge, and others. He had engineering works at Durham, from which were originated the Grange Iron Works. Besides carrying out sinkings in nearly all the English coalfields, he spent some time in Portugal exploring for coal, and also opened out a considerable number of collieries in Germany. His death took place at his residence at Carlton Miniott, near Thirsk, on 24th January 1894, in his seventy-eighth year. He became a Member of this Institution in 1868.

George Low was born at Merrion Castle, near Dublin, on 22nd April 1833. After being educated by a tutor at home, he was articled to his father's firm of bankers and stockbrokers in Dublin, his father being chairman of the Dublin and Kingstown Railway. Having shown a liking for engineering, he was apprenticed in 1854 to Messrs. William Fairbairn and Sons, Manchester. In March 1859 he went thence to manage the Canal Iron Works at Kendal for Messrs. Williamson Brothers, where he was principally engaged on making Professor James Thomson's vortex turbine. Here he brought out an engine with link motion, which the firm continued to manufacture for many years after he left. He next took the Millgate Iron Works, Newark, where he designed a rock borer and an air-compressor, which were used for boring the Roundwood Tunnel of the Dublin Corporation water works. A description of these machines was given to this Institution at the Dublin Meeting in 1865 (Proceedings, page 179). The air-compressor was of

peculiar construction; its piston worked in a body of water filling the intervening space between the piston and the compressed air. In October 1865 he went to Ipswich to take the management of the drawing office of Messrs. E. R. and F. Turner, with whom he remained about ten years, being chiefly engaged on designs in connection with steam engines, water wheels, turbines, and millwork generally. In June 1876 ill-health caused him to retire; and he devoted his time when health permitted to improving gas engines, governors, turbines, &c., and to the design of a slide-valve indicator, cranes, and drawing boards. Having been in indifferent health for many years, he died at his residence at Ipswich on 11th July 1894, at the age of sixty-one. He became a Member of this Institution in 1861.

Thomas Midelton was born at Taunton in 1848. He early showed an inclination for mechanical engineering, and after a short time spent in a lawyer's office he served his apprenticeship in the workshops of the Great Western Railway at New Swindon for five years under the late Sir Daniel Gooch and Mr. William F. Gooch. He then went to London, and obtained a situation on the Great Eastern Railway; but soon afterwards he was offered by Mr. William F. Gooch a position as draughtsman in the Vulcan Foundry. Here he designed many locomotives and gained wide experience. In 1873 he read a paper on "Patent Law Reform" before the London Society of Foremen Engineers; and the principles therein expressed have since been embodied in the patent laws. In 1884 the late Sir Alexander Stuart consulted him, and many of his suggestions were incorporated in the patent laws of New South Wales. After being assistant foreman of the Stratford running sheds of the Great Eastern Railway, and then chief foreman, he became chief engineer to the Vacuum Brake Co. He was offered the position of engineer and locomotive superintendent to the Isle of Man Railway, but preferred to take in 1876 a similar appointment on the Tasmanian Main Line Railway. In 1879 he went to New South Wales as a draughtsman in the railway department, until he was appointed locomotive overseer in 1882. After having temporary charge of the locomotive department

and the tramways he was given permanent charge of the latter in 1886. In 1888 he was promoted to be locomotive engineer, with entire charge of the locomotive and mechanical engineering branches of both the railways and the tramways; and this position he held until his retirement in 1889. His death took place at his residence in Sydney on 31st January 1894, at the age of forty-six. He became a Member of this Institution in 1886.

James Reid was born at Kilmaurs, Ayrshire, on 8th September 1823, and such education as he got was received at the village school. At the outset of his career he was engaged as a blacksmith's assistant. Then he went to Greenock, where he was employed by Messrs. Scott, Sinclair and Co., and afterwards as an engineer by Messrs. Caird and Co. Being transferred to the drawing office, he rose in 1850 to the position of chief draughtsman. In 1853 he became manager of the Hyde Park Locomotive Works, which at that time were situated in the Anderston district of Glasgow. After remaining there some years, he went to Manchester as manager of the locomotive works of Messrs. Sharp, Stewart and Co. In 1863 he returned to the Hyde Park Locomotive Works as managing partner in the firm of Messrs. Neilson and Co., in succession to Mr. Henry Dübs, who had started the Glasgow Locomotive Works at Polmadie. During his stay in Manchester the Hyde Park Works had been transferred in 1860 to Springburn; and under his direction these became the largest locomotive establishment in private hands in the country. In 1863 about 1,000 men were employed here, and the number of engines turned out was 78 annually; lately the number of men employed had increased to about 2,600, and the output to over 200 locomotives a year. In 1878 he became by purchase the sole proprietor of the works; and in 1893 took into partnership his four sons. In 1877 he became a member of the Town Council, and in 1893 was elected Lord Dean of Guild by the Merchants' House, of which body he had long been a member. He was also president of the Fine Art Institute, president of the Institution of Engineers and Shipbuilders in Scotland, a member of the Institution of Civil Engineers, and a justice of the peace for the counties of Lanark and Perth. His

death occurred suddenly at St. Andrews from failure of the heart on 23rd June 1894, in his seventy-first year. He became a Member of this Institution in 1883.

Charles Willman, son of Mr. T. L. Willman a celebrated clarionet player, was born in London on 24th April 1832. He was educated at King Edward's Grammar School, Birmingham, and subsequently at a military and naval college in France; and was then articled to a civil and mining engineer in Staffordshire. Afterwards, with a view to gaining a thorough knowledge of the world, he entered the navy as an ordinary seaman, and served throughout the Crimean war, rising to the position of a first-class petty officer, and receiving three medals. He subsequently joined the naval brigade, and was present at the battle of the Baltic, and afterwards went to the Black Sea. He also served in the 12th Lancers. After the war he was engaged in the construction of the Riga and Dunaberg Railway. In 1864 he went to Middlesbrough in the service of Mr. R. C. May, and assisted in valuing Messrs. Bolckow and Vaughan's works. He next became erecting engineer to Messrs. Hopkins, Gilkes and Co., with whom he stayed five years. He was also concerned in the construction of the handsome high-level bridge at Saltburn, crossing over the deep glen which contains the gardens. In 1868 he withdrew from the engineering profession and became an auctioneer, in partnership with Mr. Thomas T. Douglas. For eight years he was a member of the Town Council of Middlesbrough, and was Mayor during 1881, when the town celebrated its jubilee. Having been in failing health for some time, he died at his residence at Coatham, Redcar, on 9th April 1894, in his sixty-second year. He became a Member of this Institution in 1870; and was also an Associate Member of the Institution of Civil Engineers, a Member of the Iron and Steel Institute, and of the Institution of Cleveland Engineers.

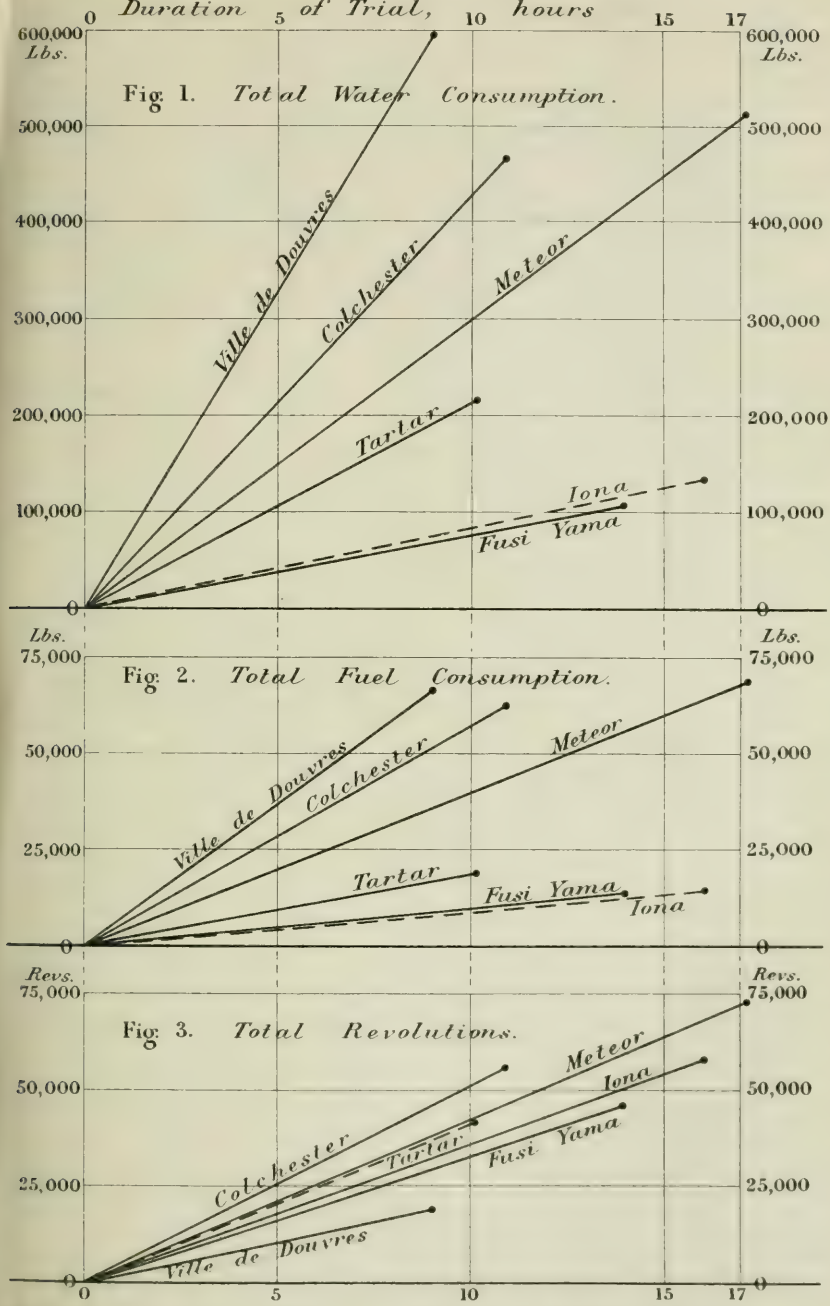
INDEX.

1894.
Parts 1–2.

MARINE-ENGINE TRIALS.

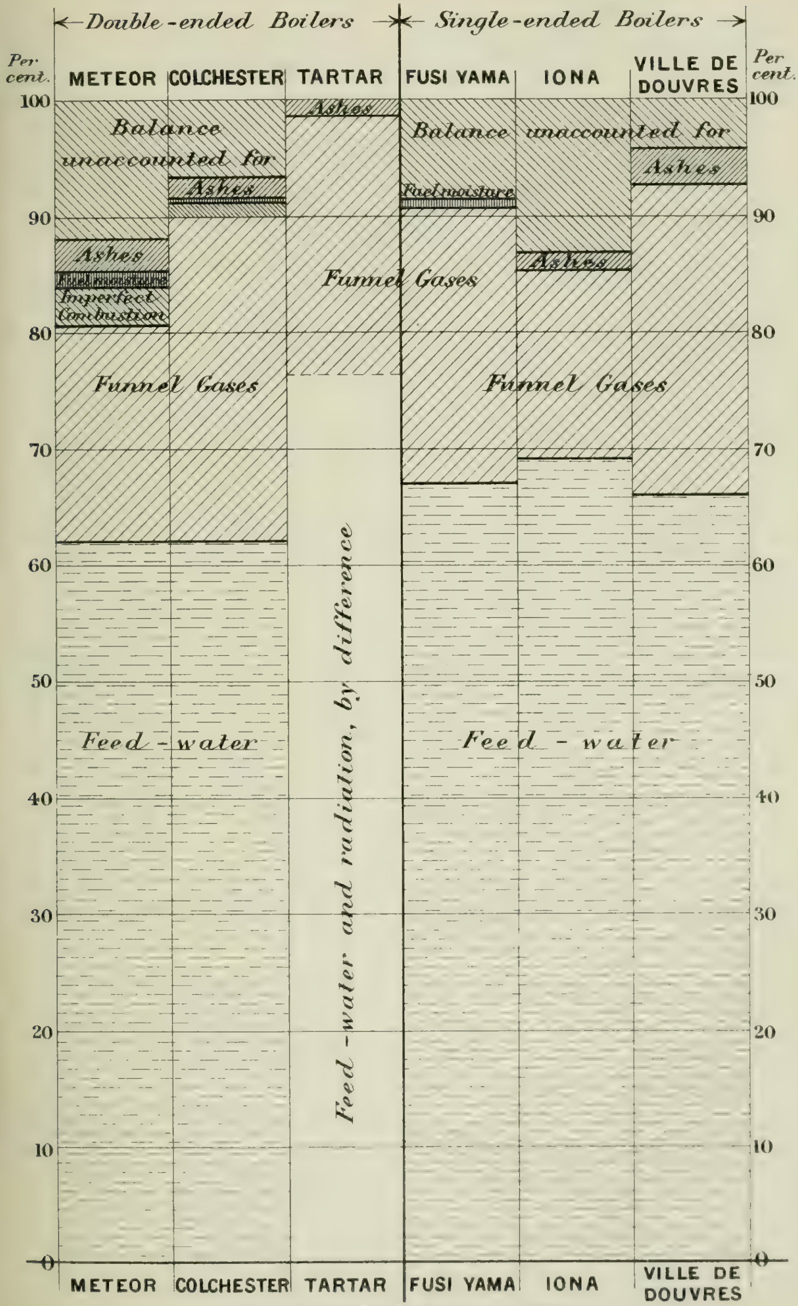
Plate 1.

Total Water, Fuel, and Revolutions.



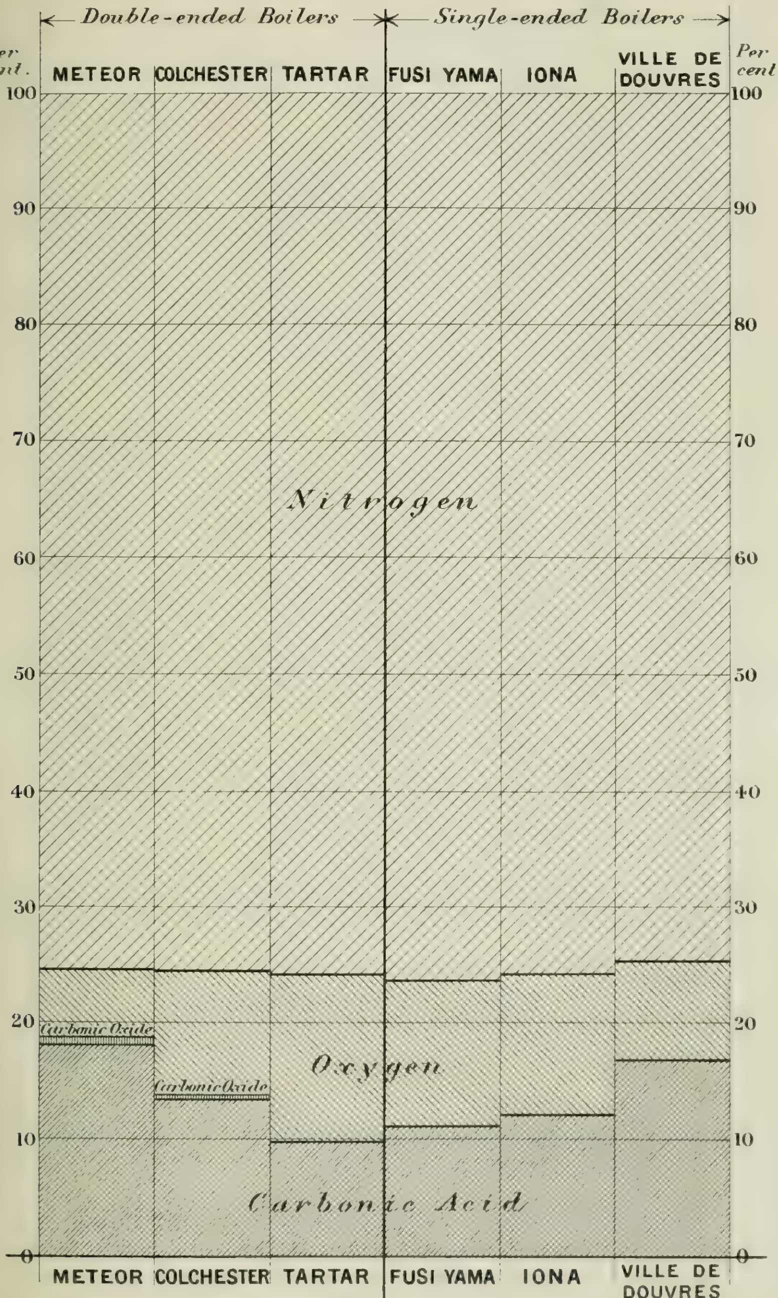
Mechanical Engineers 1894. *Duration of Trial, hours.*

Fig. 4. *Heat Balance-sheet.* *See Table 18.*

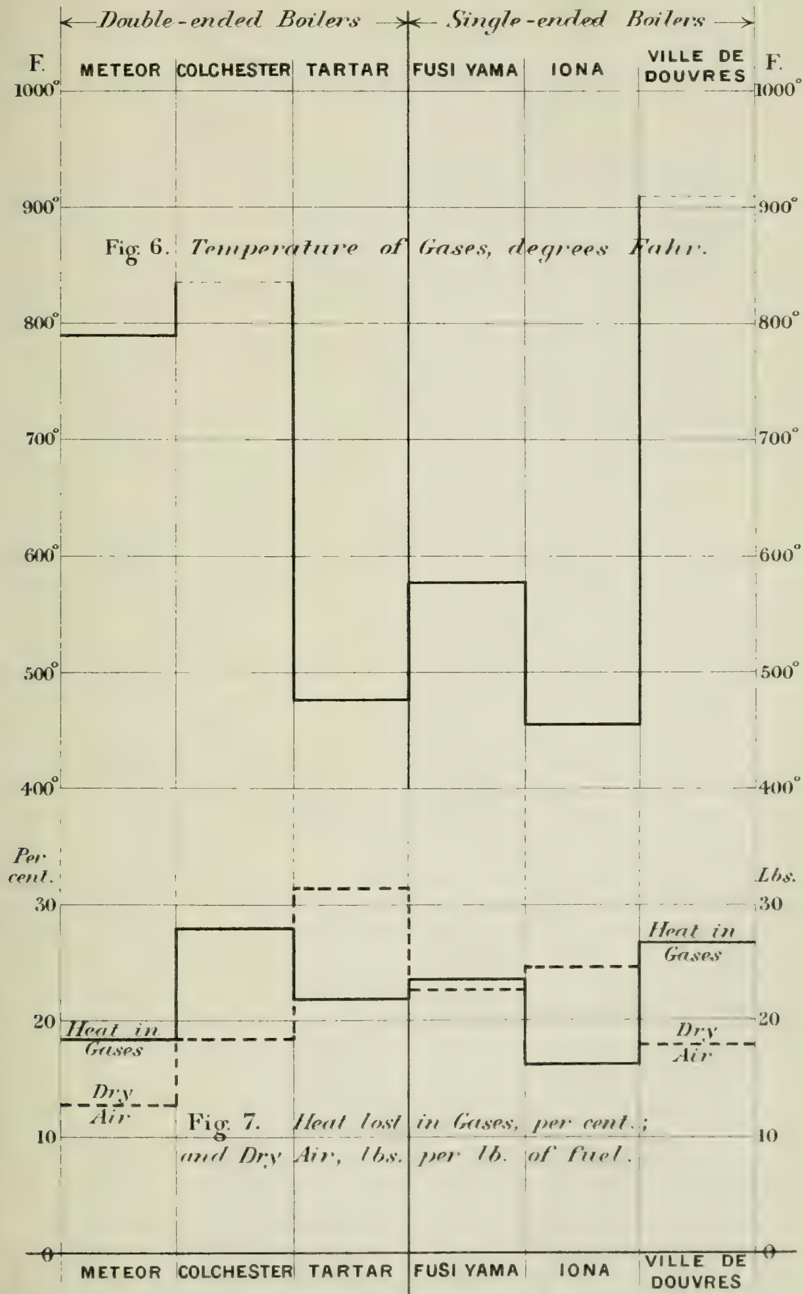


MARINE-ENGINE TRIALS. *Plate 3.*

Fig. 5. *Analyses of Funnel Gases.* *See Table 22.*



Temperature and Heat of Funnel Gases. See Table 22.



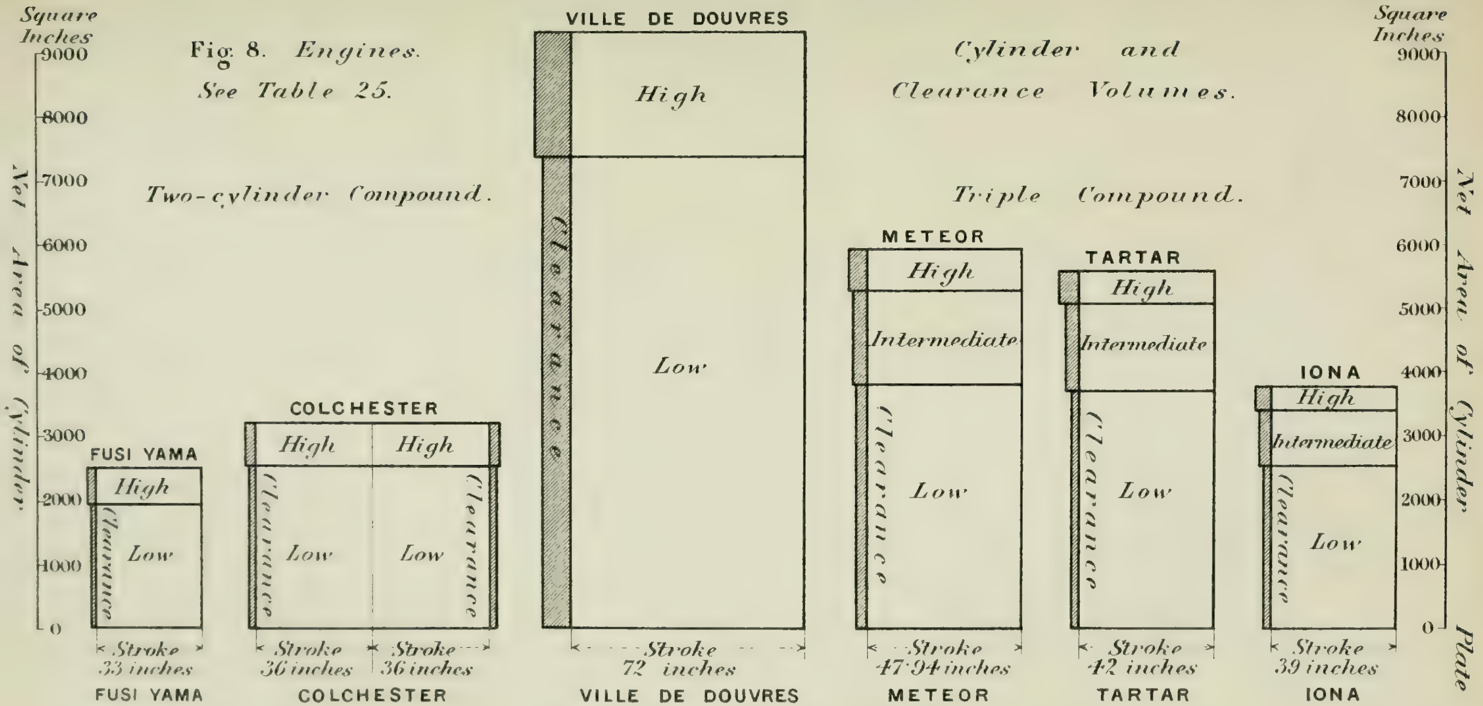
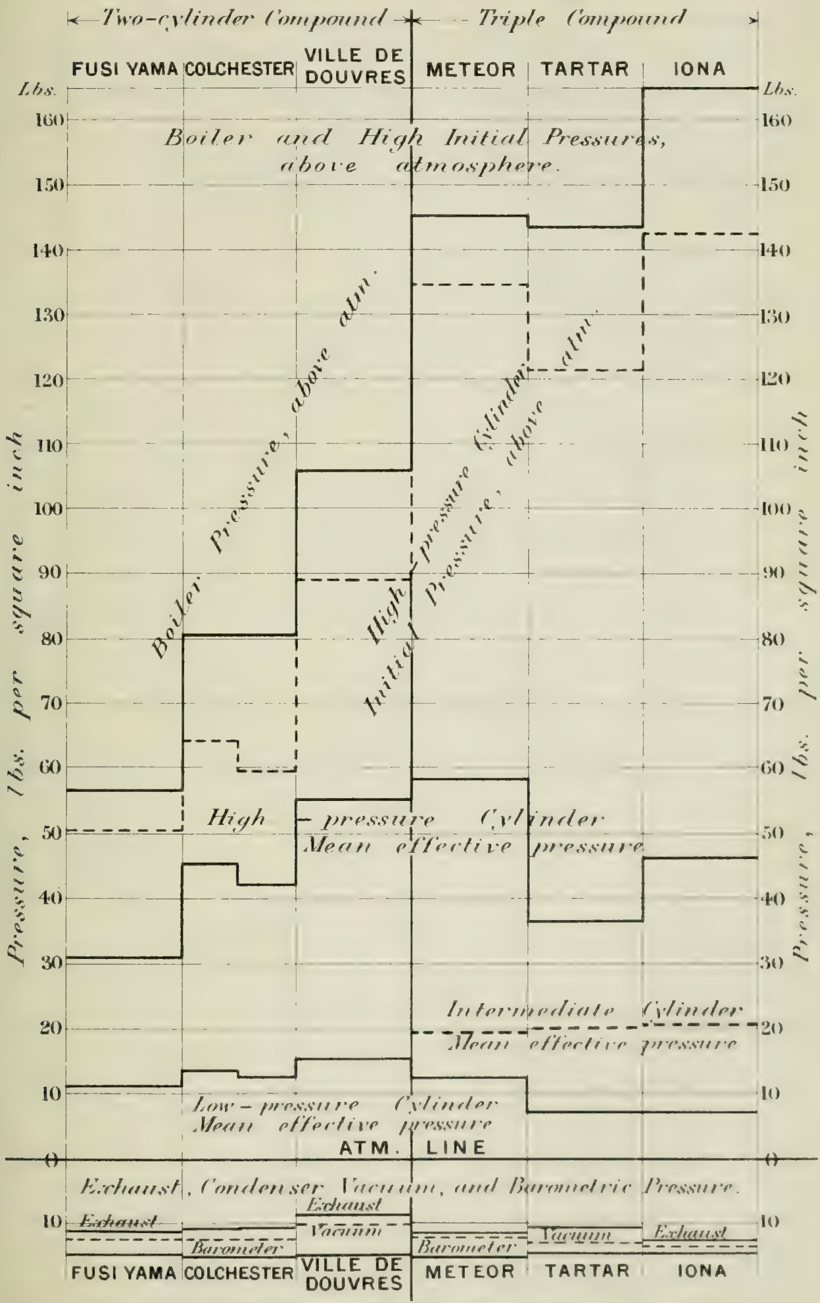

Square Inches
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Net Area of Cylinder
Fig. 8. Engines.
See Table 25.
Two-cylinder Compound.
Cylinder and Clearance Volumes.
Triple Compound.
FUSI YAMA
High
Low
Clearance
Stroke 33 inches
COLCHESTER
High
Low
Clearance
Stroke 36 inches
High
Low
Clearance
Stroke 36 inches
VILLE DE DOUVRES
High
Low
Clearance
Stroke 72 inches
METEOR
High
Intermediate
Low
Clearance
Stroke 47·94 inches
TARTAR
High
Intermediate
Low
Clearance
Stroke 42 inches
IONA
High
Intermediate
Low
Clearance
Stroke 39 inches
Plate 5.

Fig. 9. *Steam Pressures. See Table 26.*



MARINE-ENGINE TRIALS.

Fig. 10. *Indicator Diagrams. See Tables 26 and 30.*

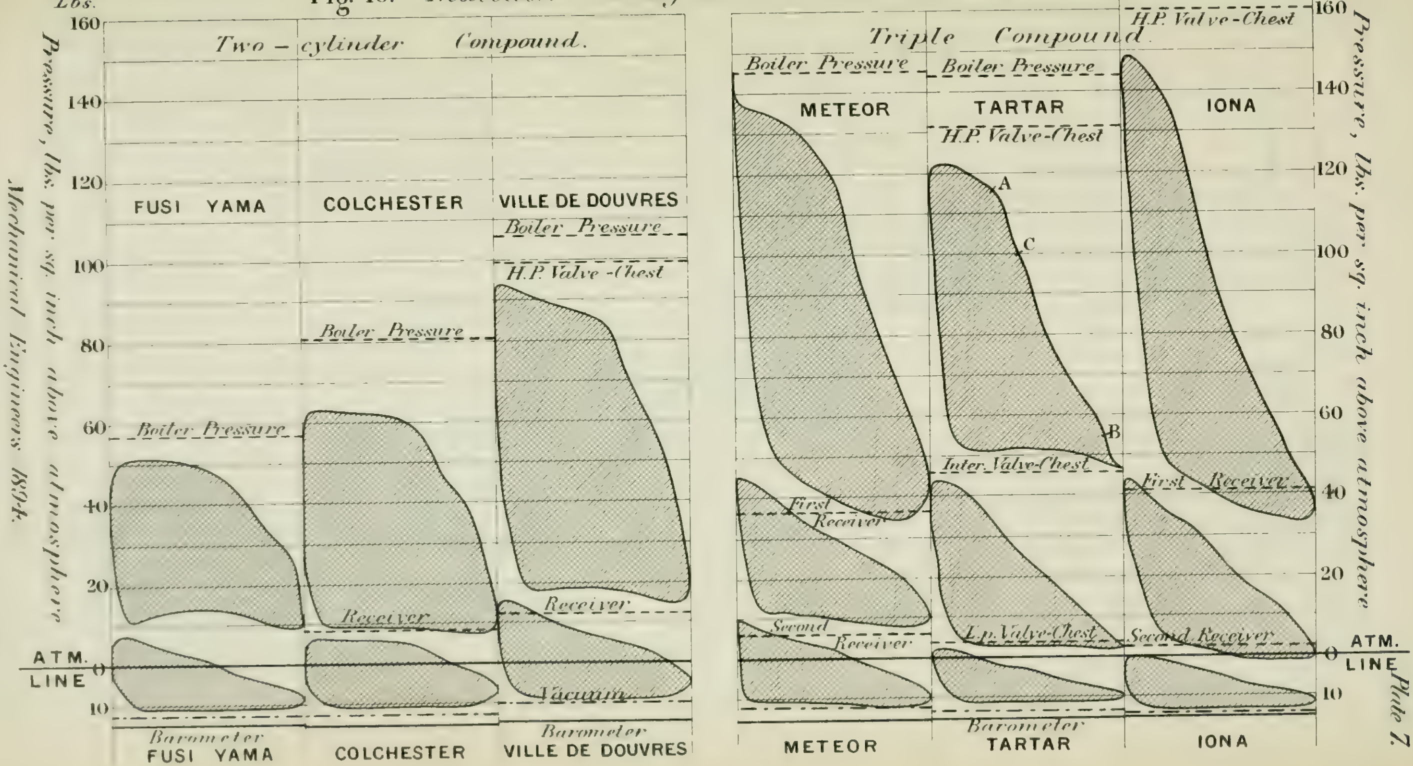
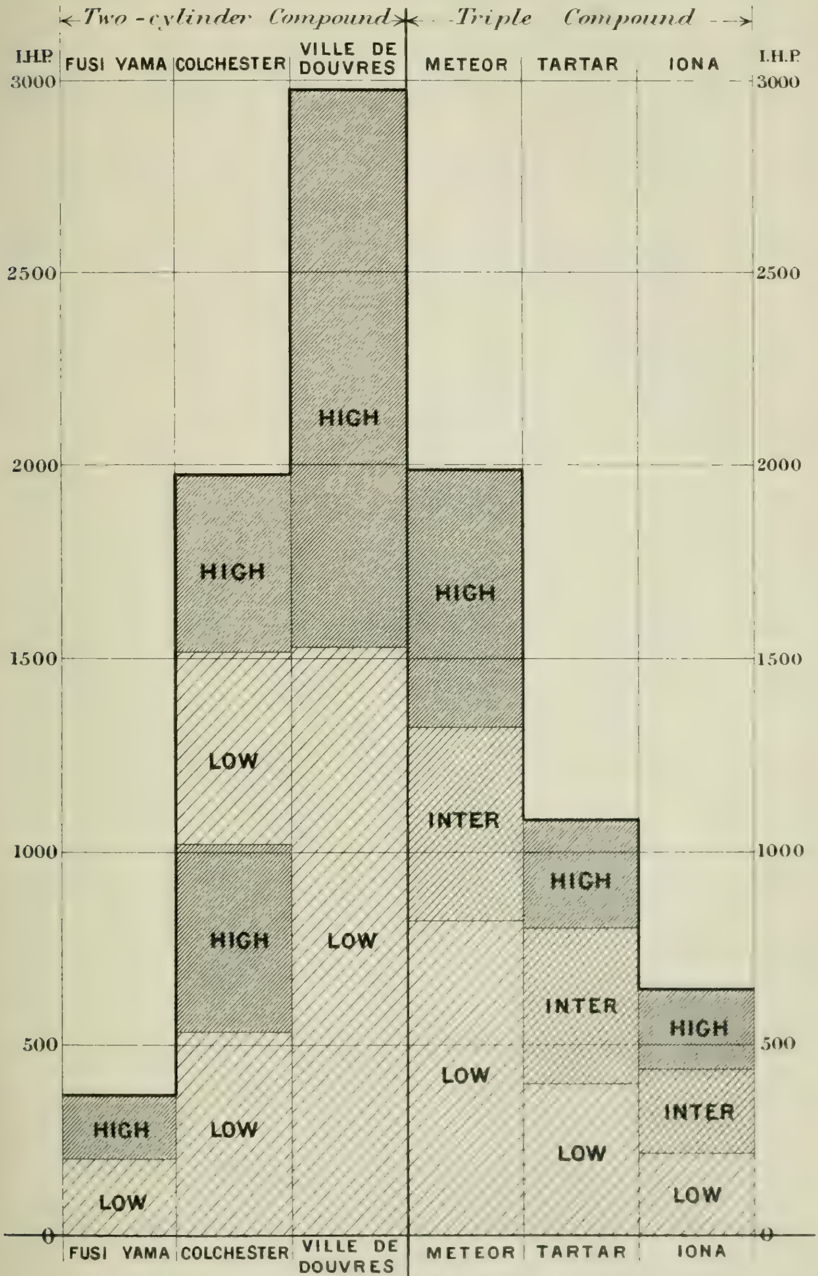


Plate 7.

Fig. 11. *Indicated Horse-power. See Table 27.*



MARINE-ENGINE TRIALS. *Plate 9.*

Fig. 12. *Feed-Water, Engine Efficiency, and Carbon-value.*
See Tables 29 and 18.

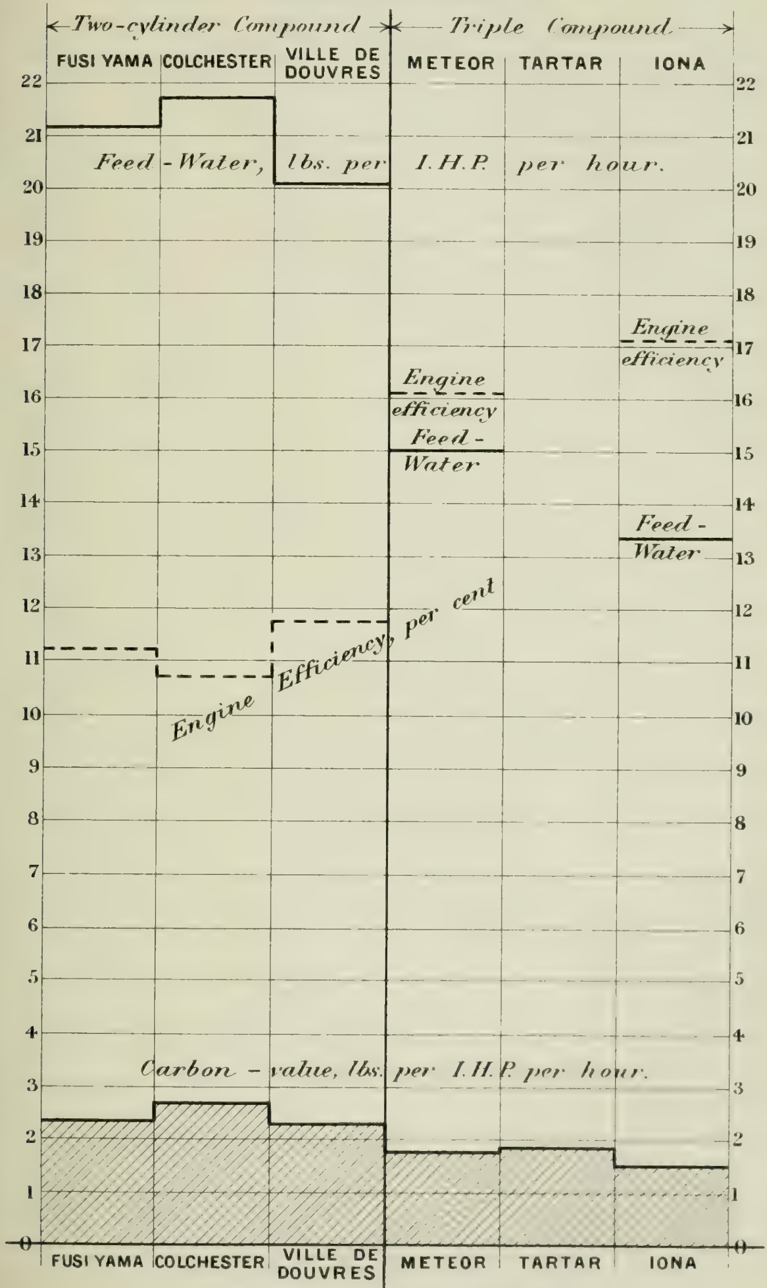


Fig. 13. *Percentage of total feed present as Steam in Cylinders at different points in stroke. See Table 32.*

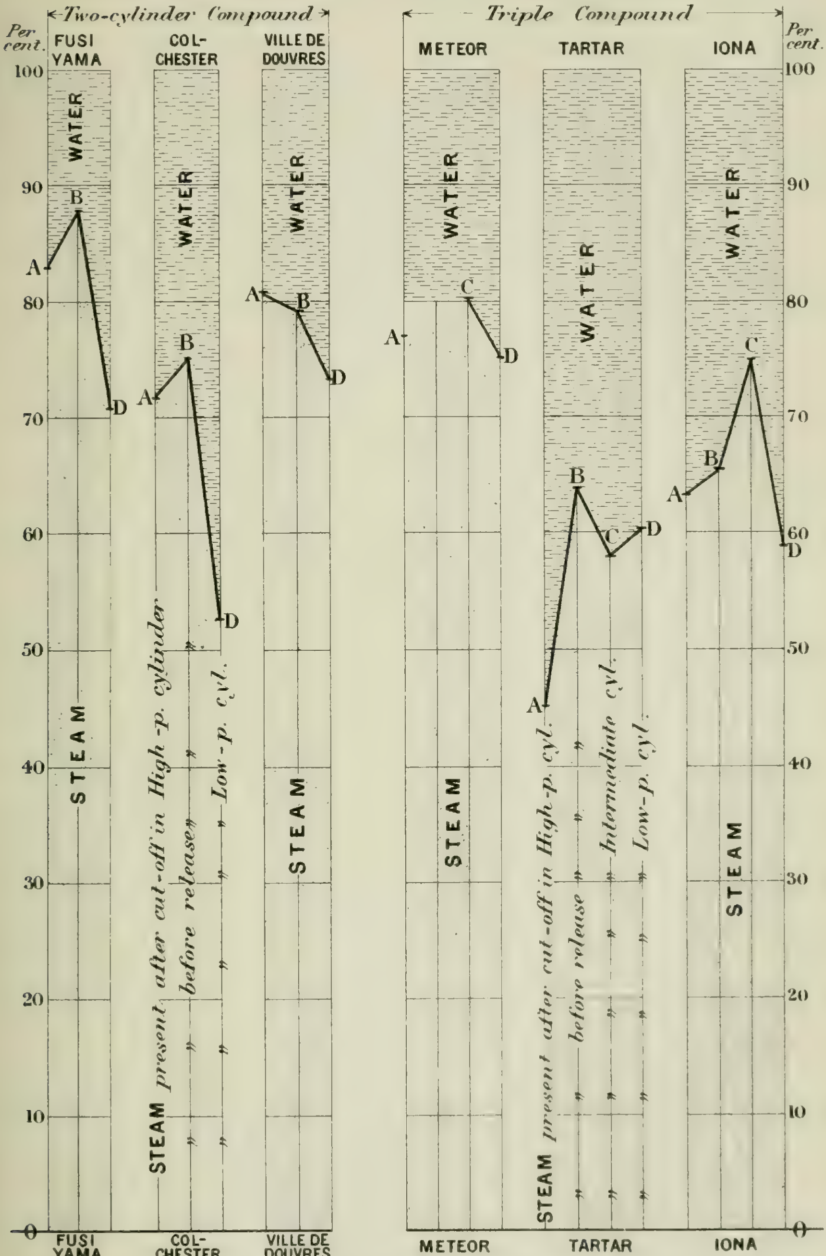


Fig. 14. *Clearance plus cylinder surfaces exposed to steam at point of Cut-off. See Table 33.*

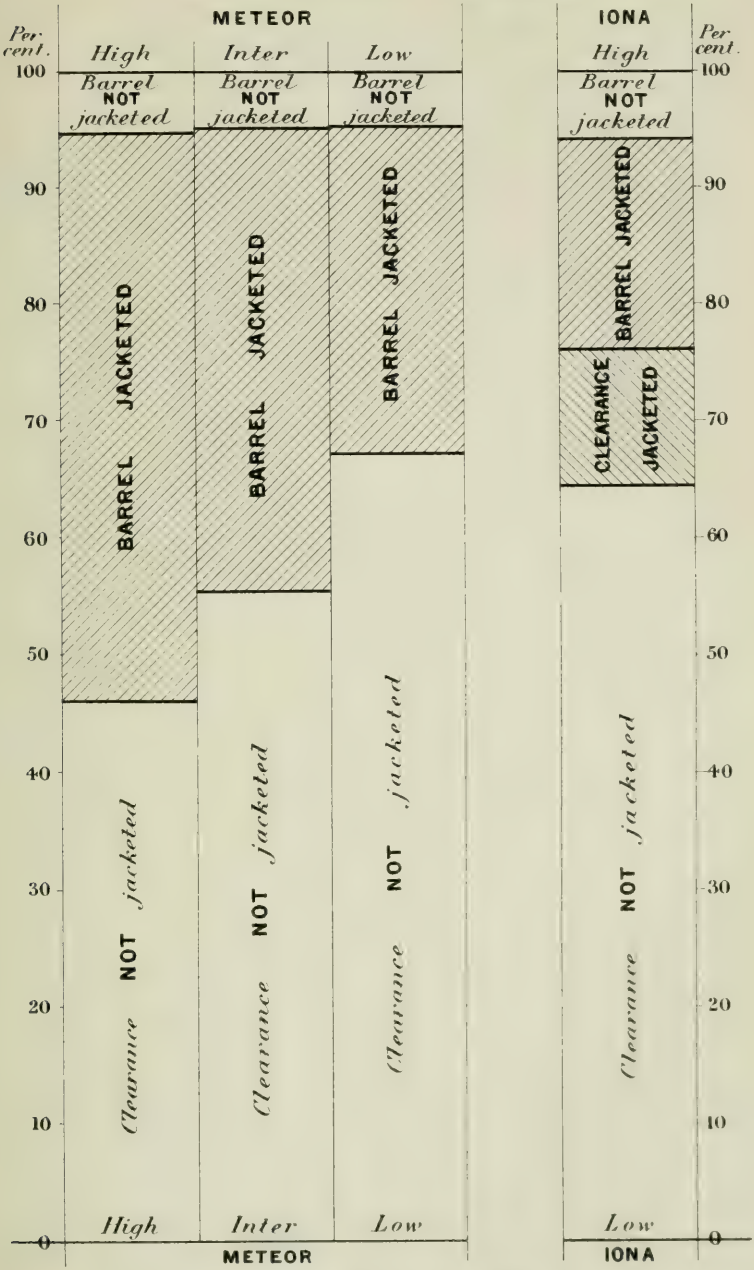
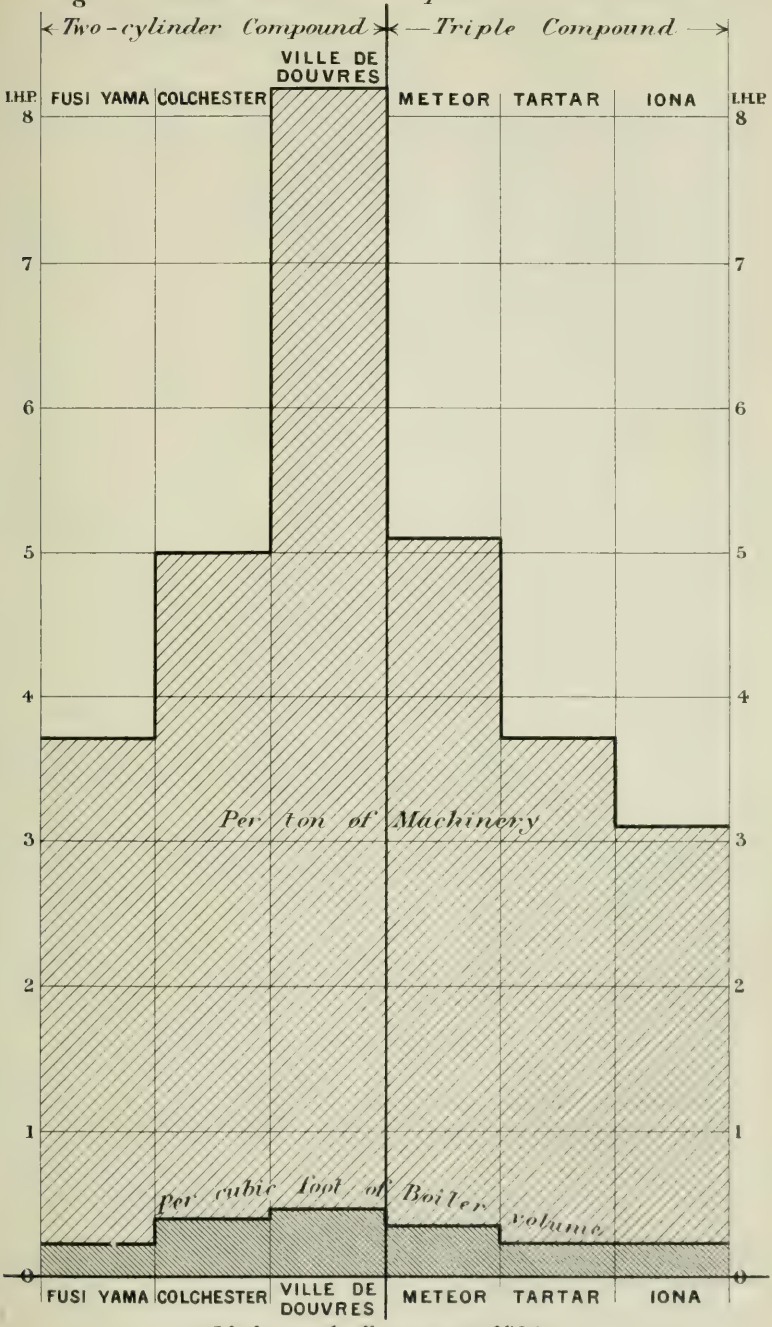
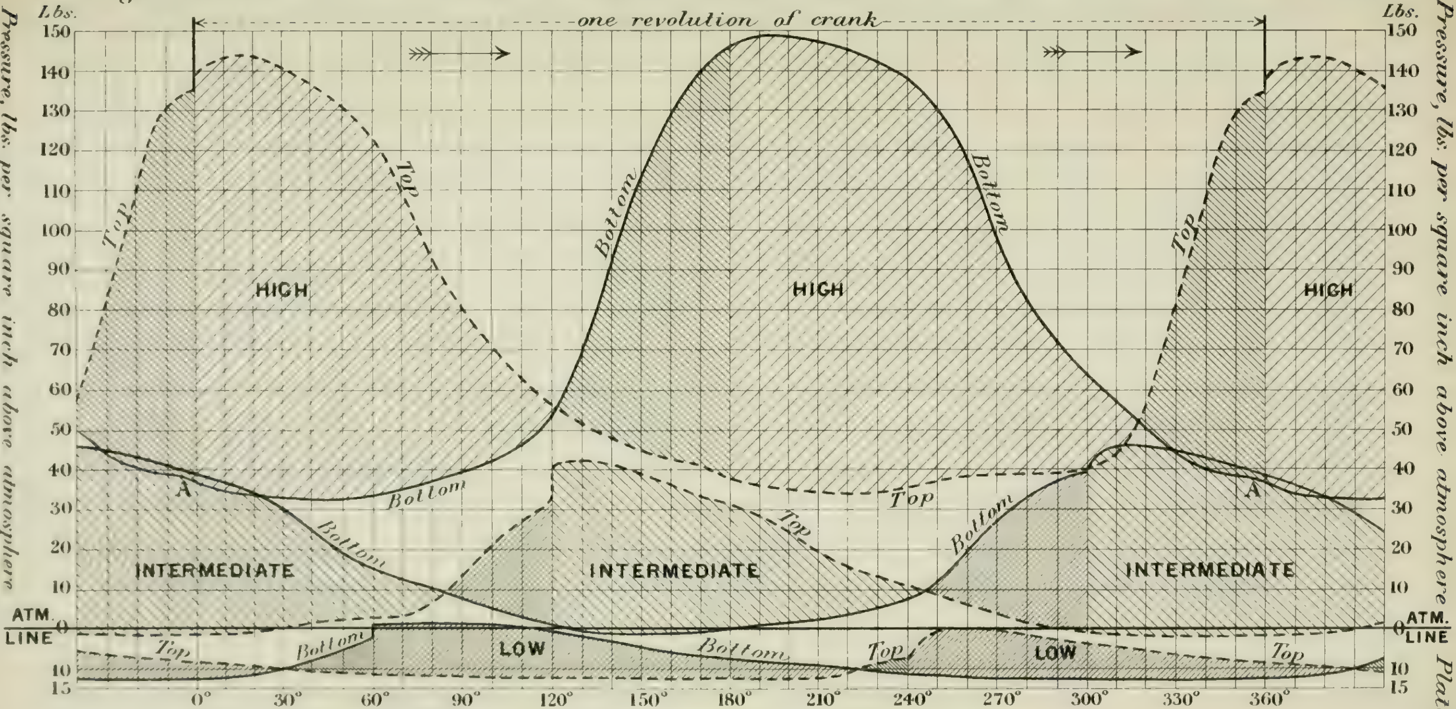


Fig. 15. *Indicated Horse-power. See Table 34.*



MARINE - ENGINE TRIALS.

Fig. 16. *Continuous Development of Indicator Diagrams from "Iona." See Plate 46, Proceedings 1891.*



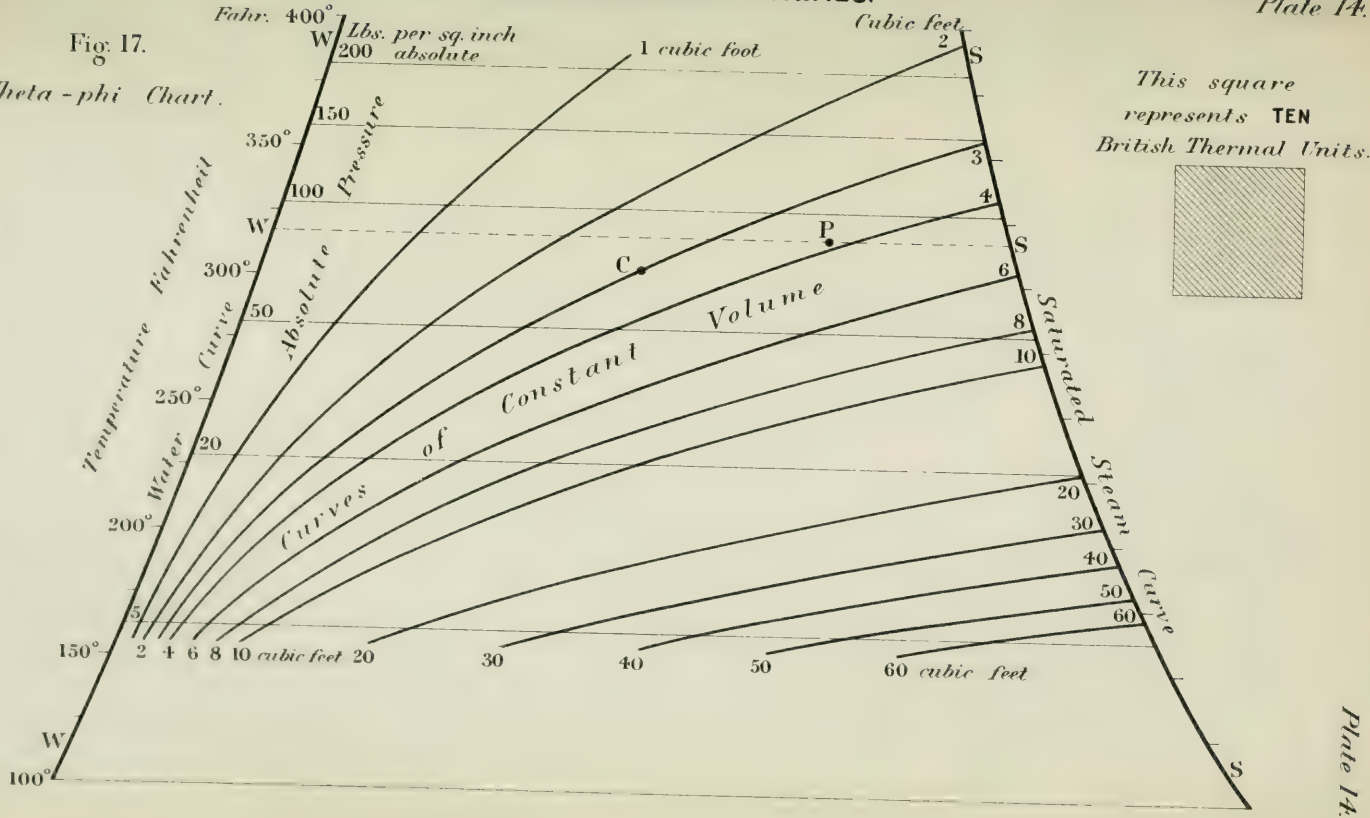
Degrees in Revolution of High-Pressure Crank

Mechanical Engineers 1894.

MARINE-ENGINE TRIALS.

Fig. 17.

Theta-phi Chart.



MARINE-ENGINE TRIALS.

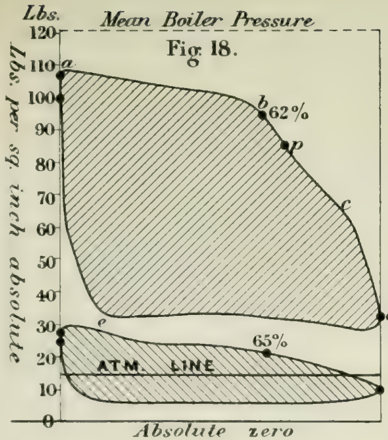
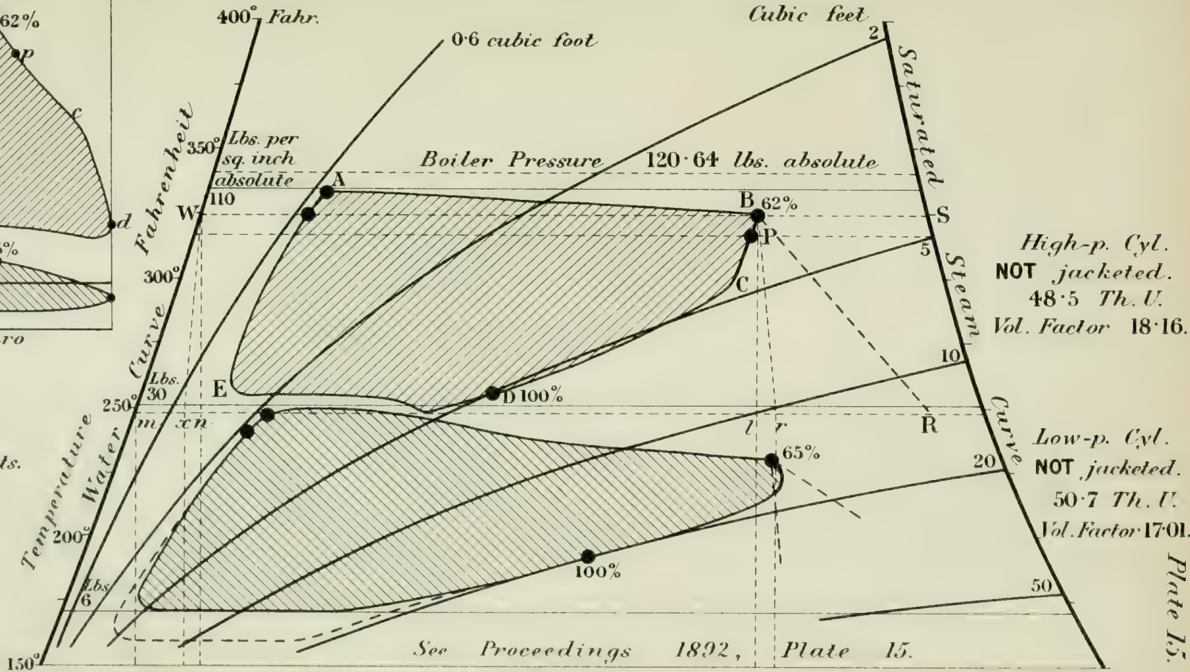
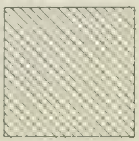


Fig. 19. *Theta-phi Diagrams of "Ville de Douvres."*



This square represents **TEN** British Thermal Units.

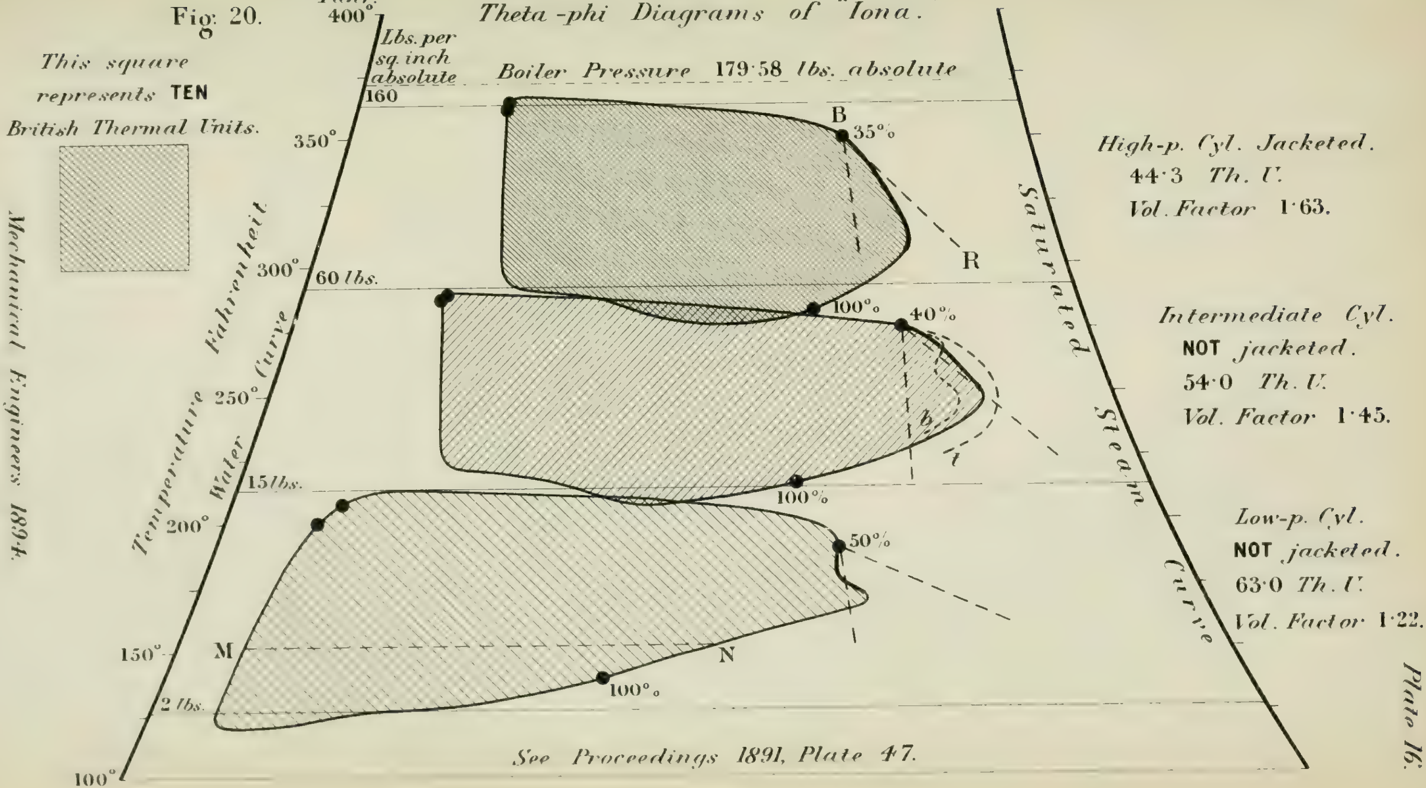


Mechanical Engineers 1894.

MARINE-ENGINE TRIALS.

Fig. 20.

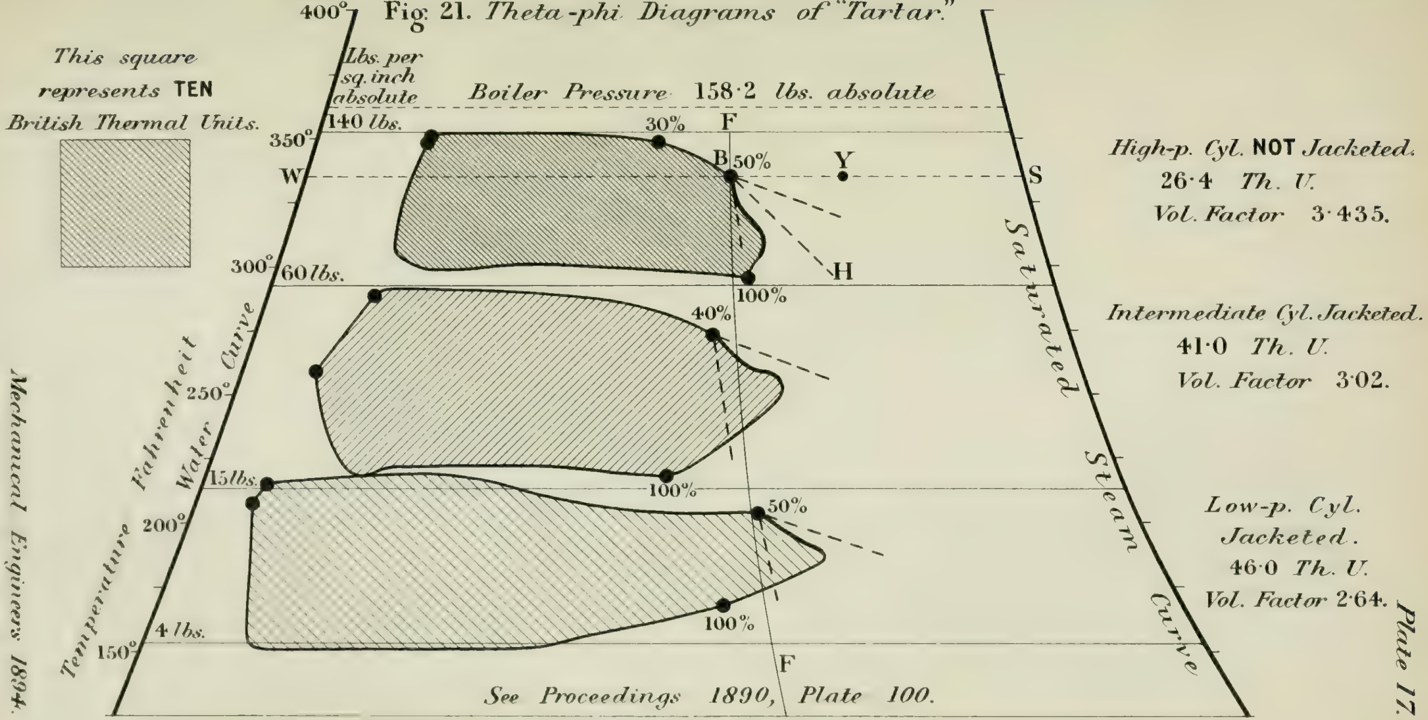
Theta-phi Diagrams of "Iona."



See Proceedings 1891, Plate 47.

Plate 16.

Fig. 21. *Theta-phi Diagrams of "Tartar."*

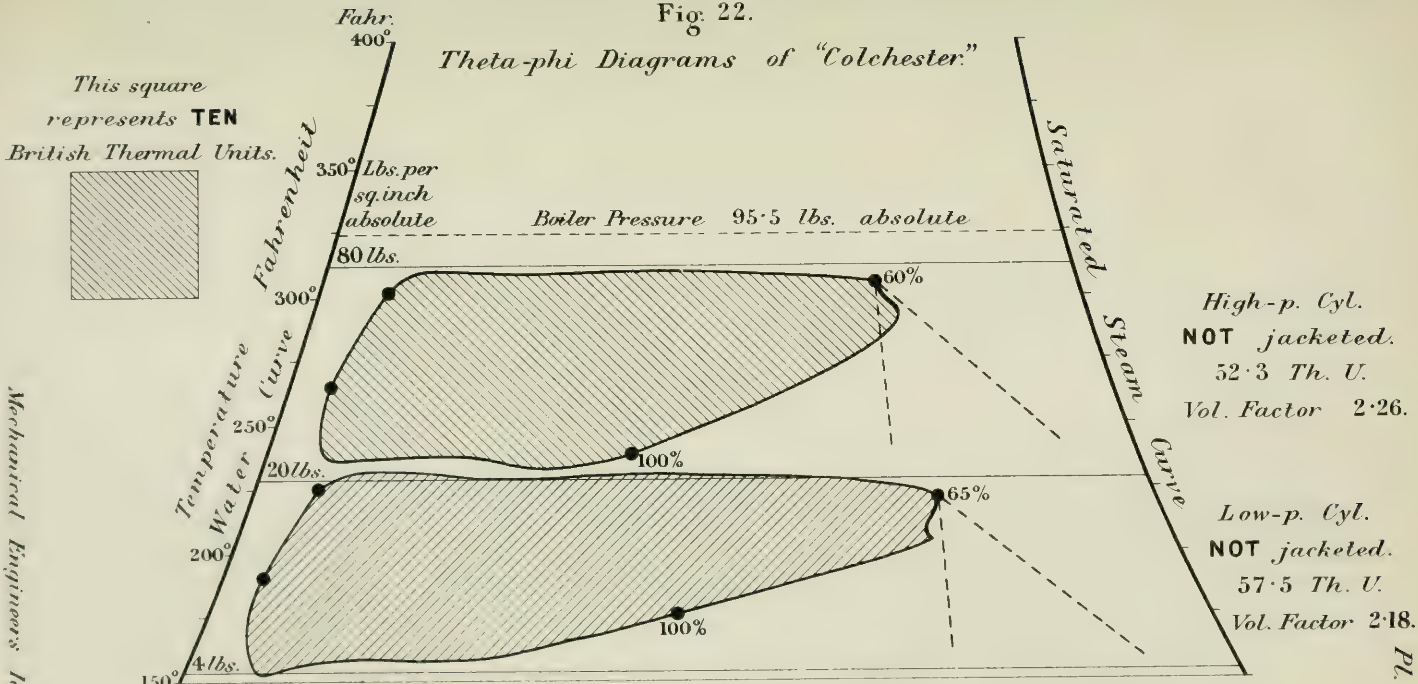


See Proceedings 1890, Plate 100.

MARINE-ENGINE TRIALS.

Fig. 22.

Theta-phi Diagrams of "Colchester."



See Proceedings 1890, Plate 96.

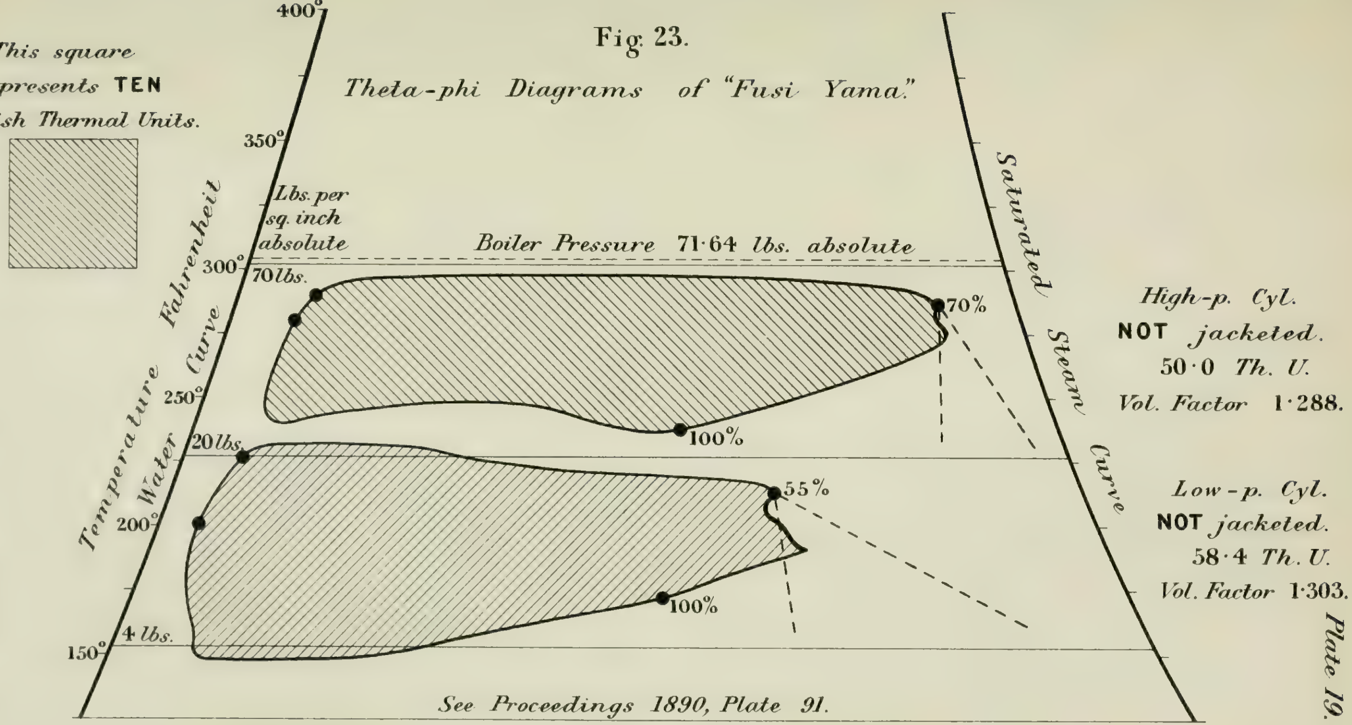


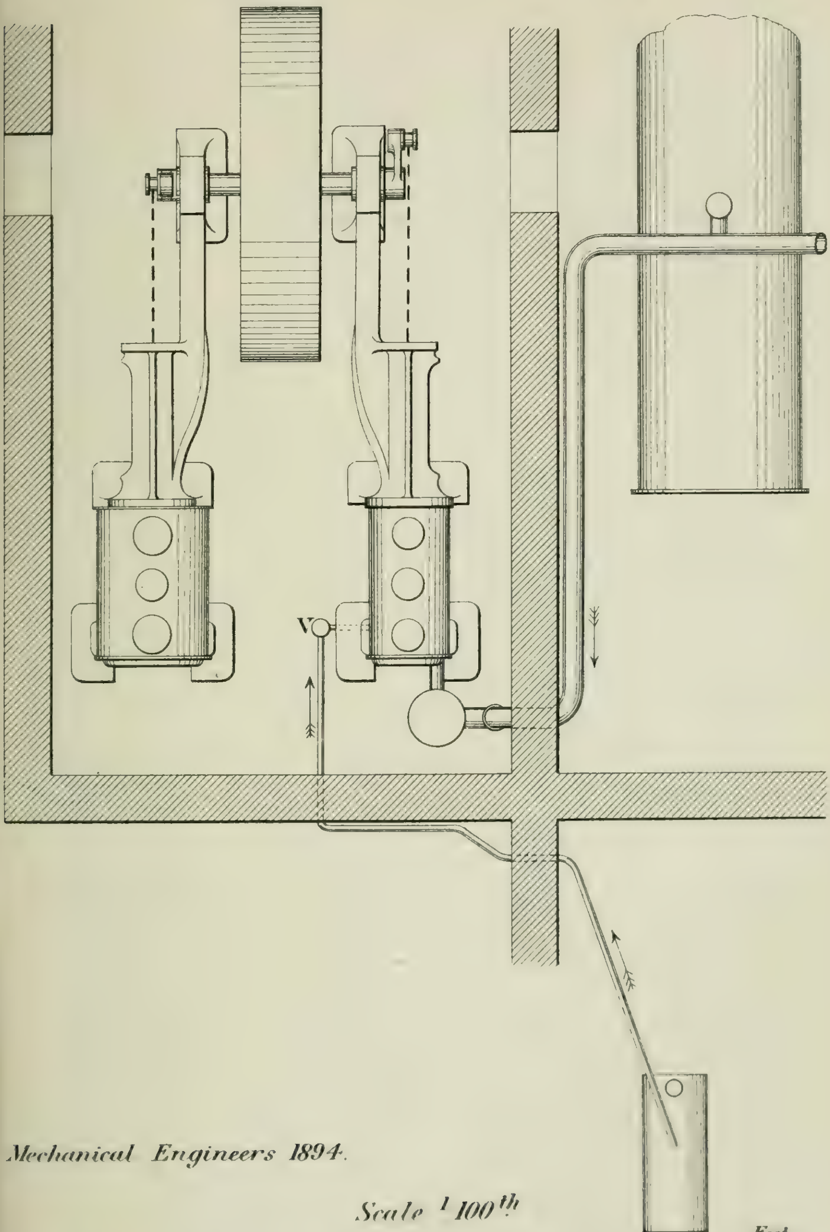
Fig: 23.

Theta-phi Diagrams of "Fusi Yama."

See Proceedings 1890, Plate 91.

Plate 19.

Fig. 1. *Arrangement of Experimental Apparatus.*



Mechanical Engineers 1894.

Scale 1/100th

Auxiliary Valve Gear.

Fig. 2. *Plan.*

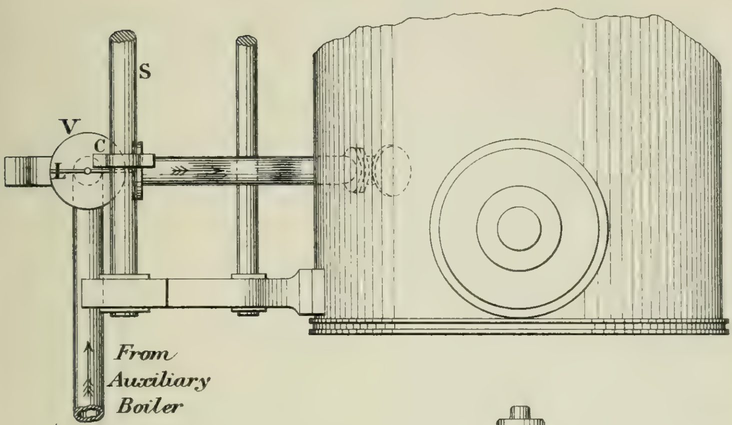
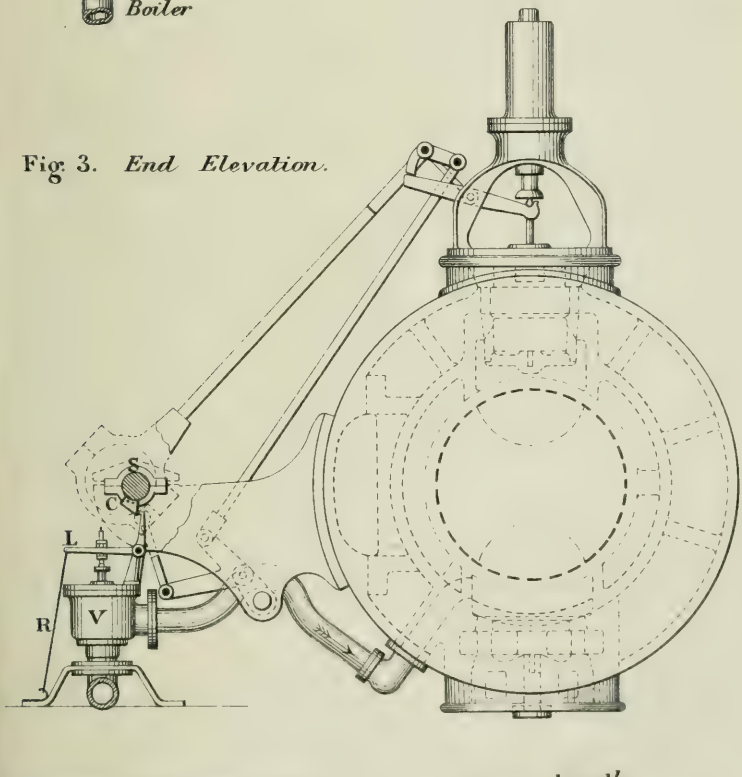


Fig. 3. *End Elevation.*

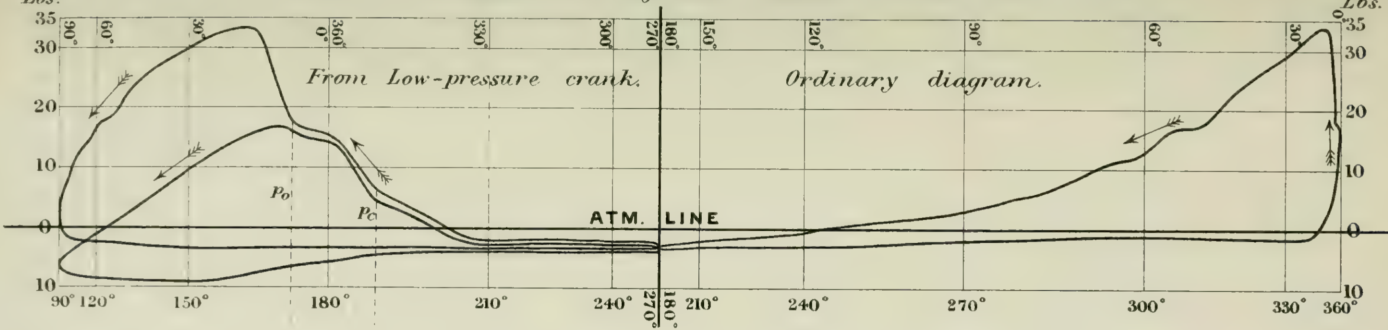


 Scale 1/20th.

Ins. 12 6 0 1 2 3 4 5 Ft.

INITIAL CONDENSATION.

Trial 3. Indicator Diagrams taken 3 Feb. 1893.



Trial 4. Indicator Diagrams taken 8 Feb. 1893.

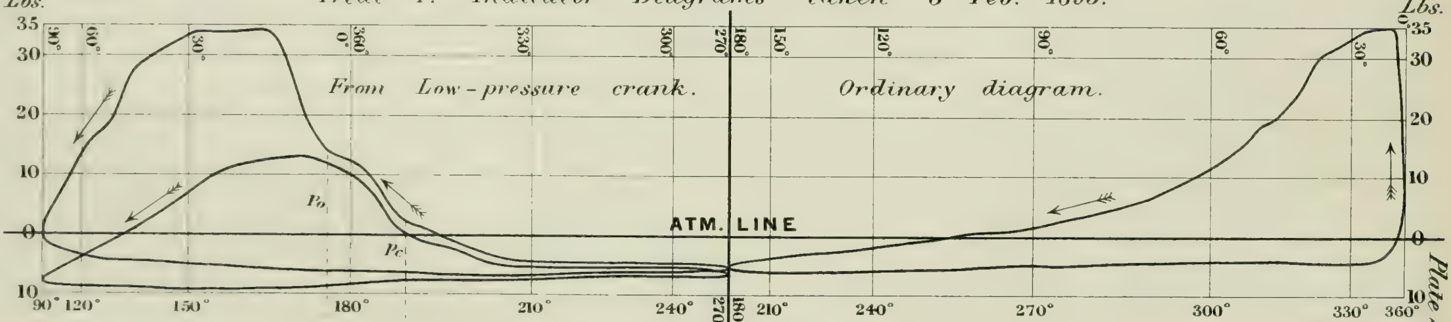
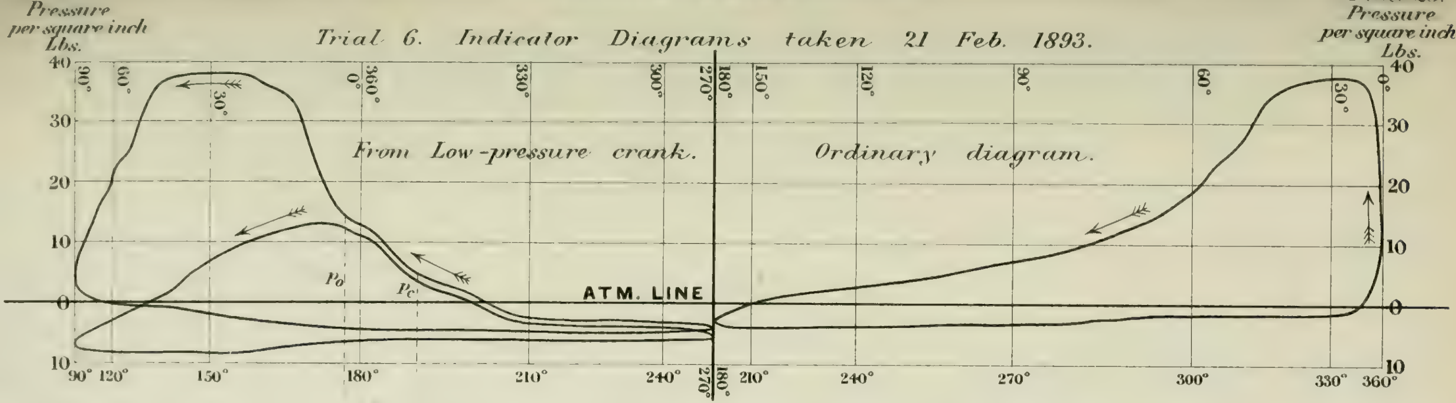


Plate 22.

INITIAL CONDENSATION.

Trial 6. Indicator Diagrams taken 21 Feb. 1893.



Trial 7. Indicator Diagrams taken 28 Feb. 1893.

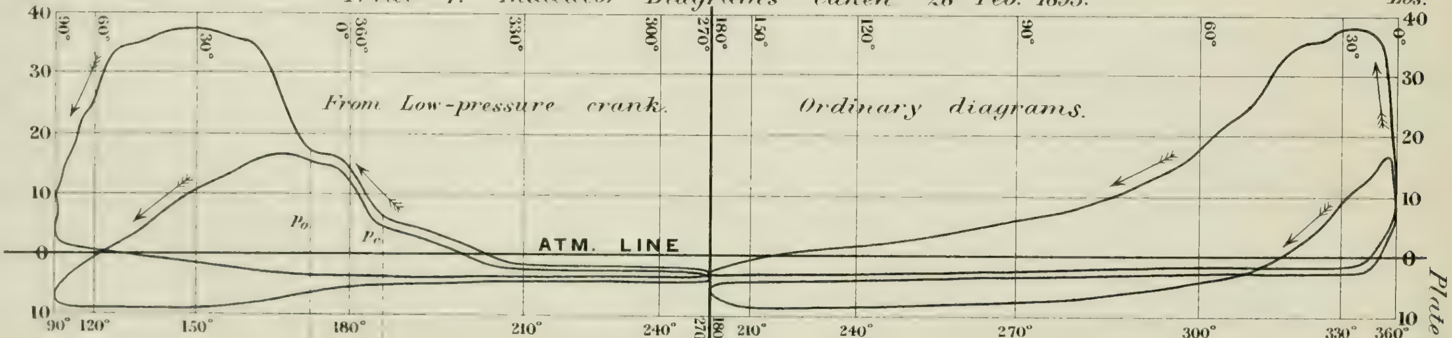
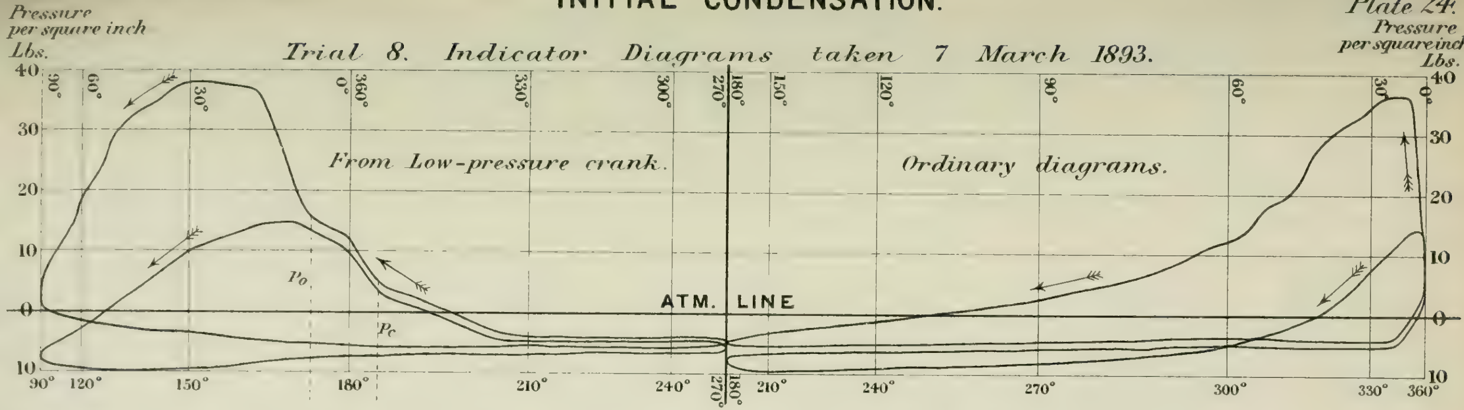


Plate 23.

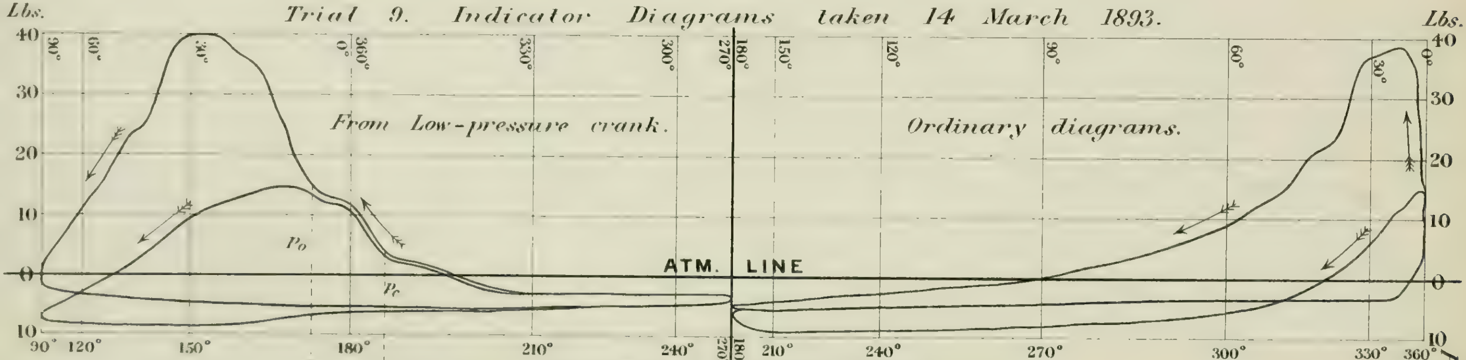
INITIAL CONDENSATION.

Plate 24.

Trial 8. Indicator Diagrams taken 7 March 1893.



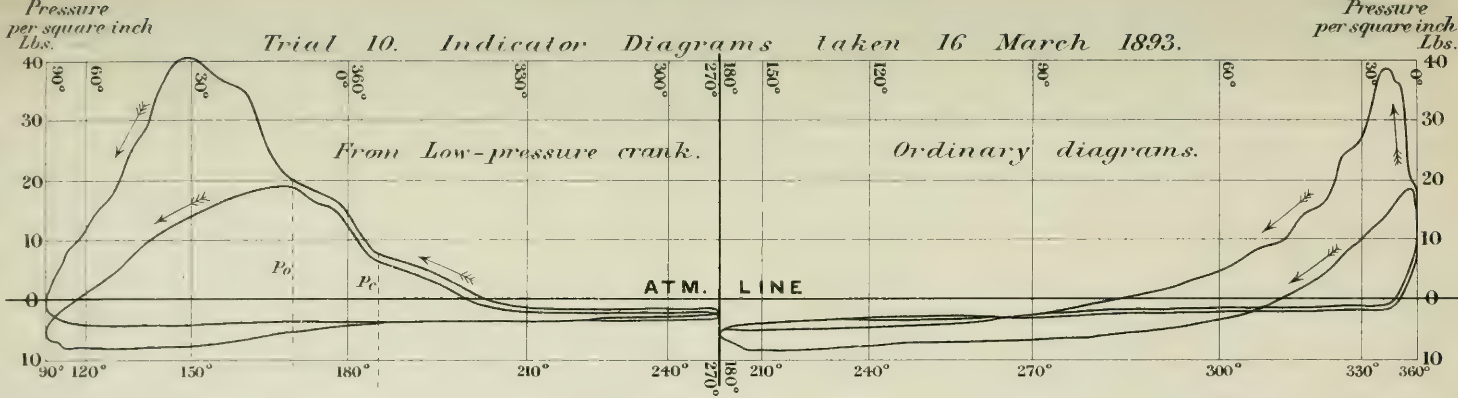
Trial 9. Indicator Diagrams taken 14 March 1893.



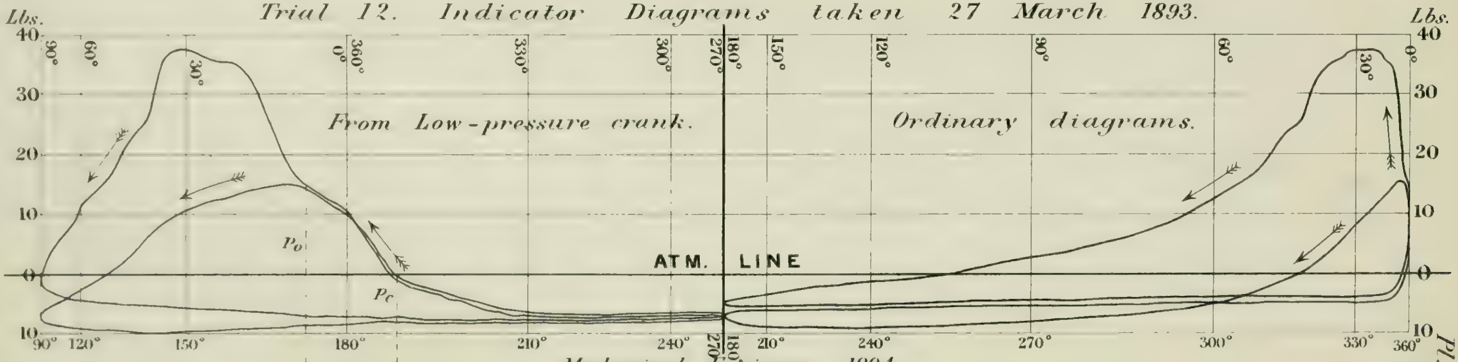
INITIAL CONDENSATION.

Plate 25.

Trial 10. Indicator Diagrams taken 16 March 1893.

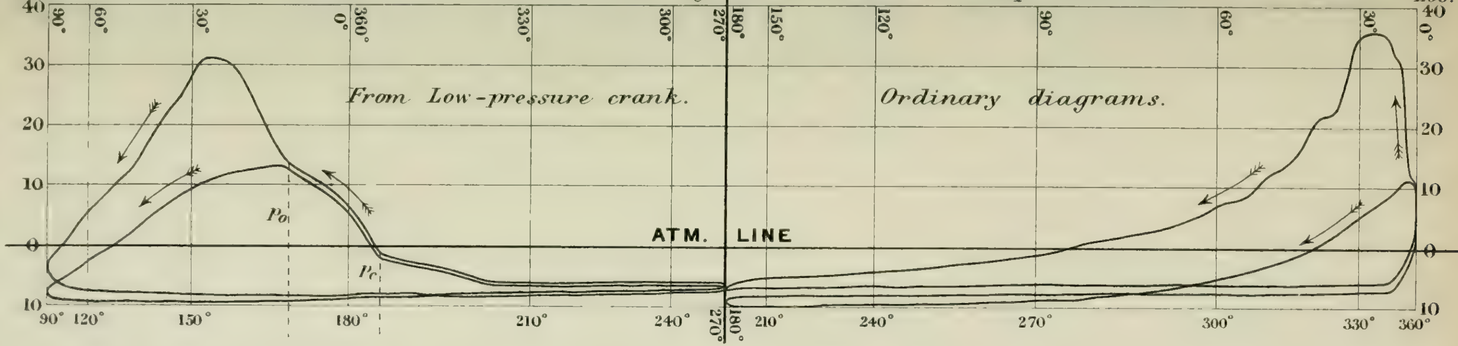


Trial 12. Indicator Diagrams taken 27 March 1893.

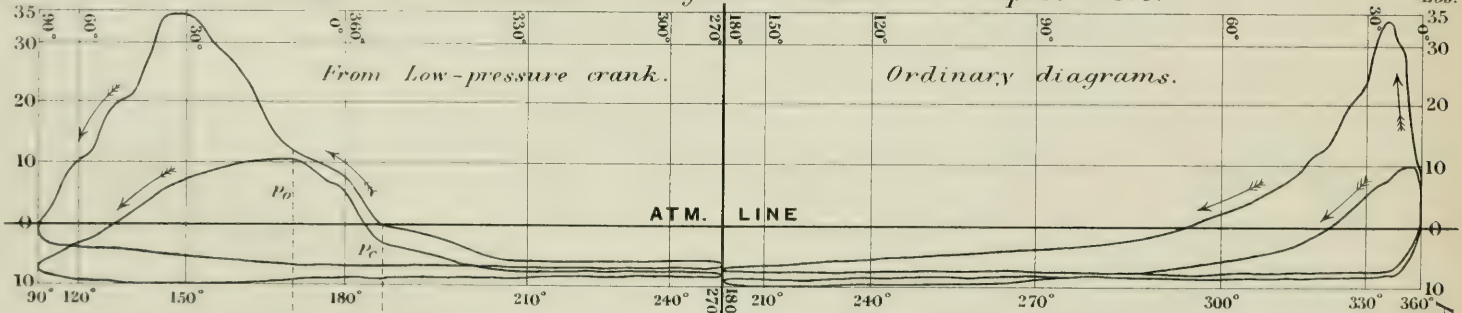


INITIAL CONDENSATION.

Trial 14. Indicator Diagrams taken 13 April 1893.



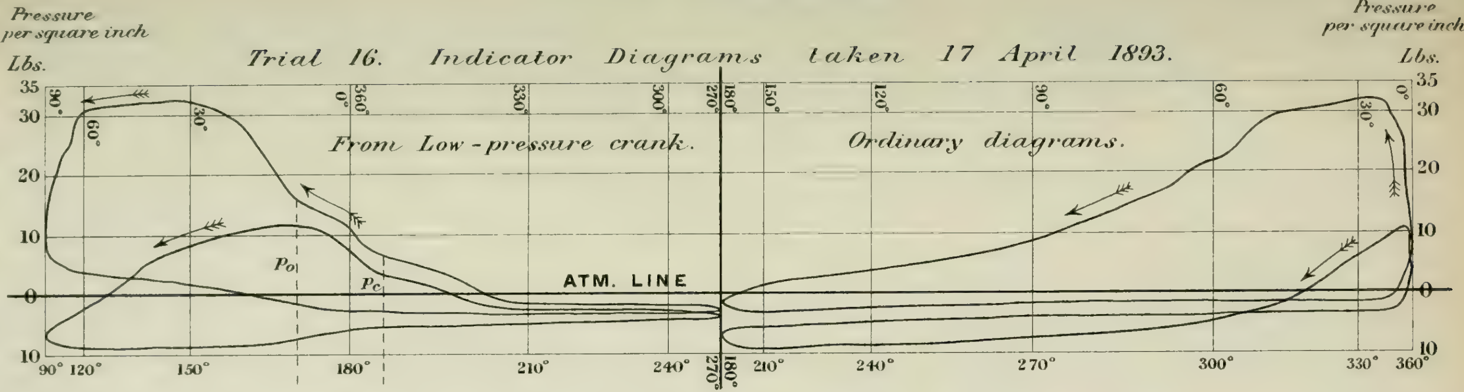
Trial 15. Indicator Diagrams taken 14 April 1893.



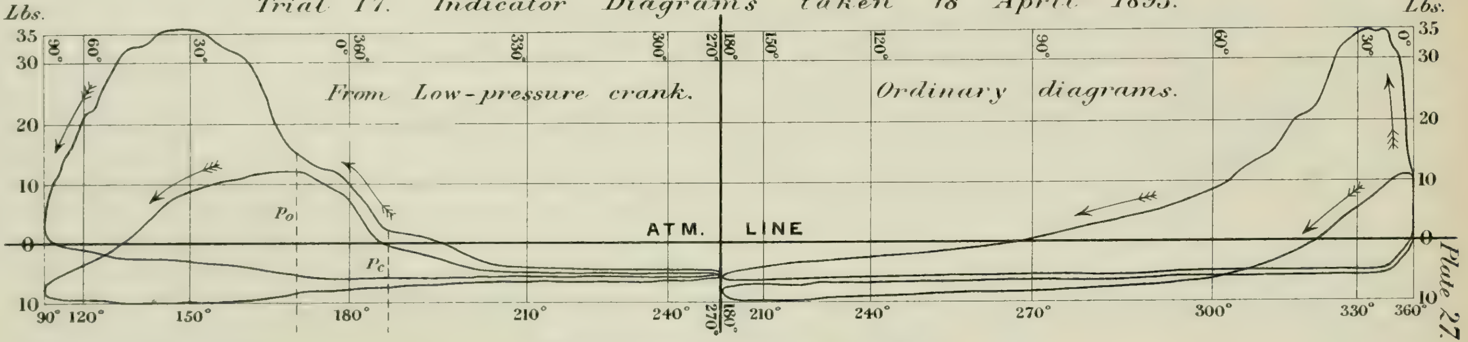
INITIAL CONDENSATION.

Plate 27.

Trial 16. Indicator Diagrams taken 17 April 1893.

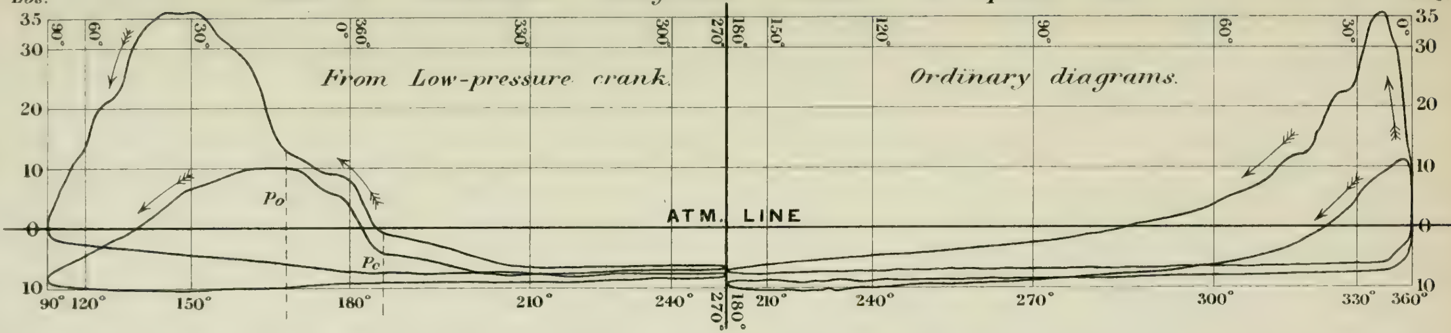


Trial 17. Indicator Diagrams taken 18 April 1893.



INITIAL CONDENSATION.

Trial 18. Indicator Diagrams taken 20 April 1893.



Trial 22. Indicator Diagrams taken 28 April 1893.

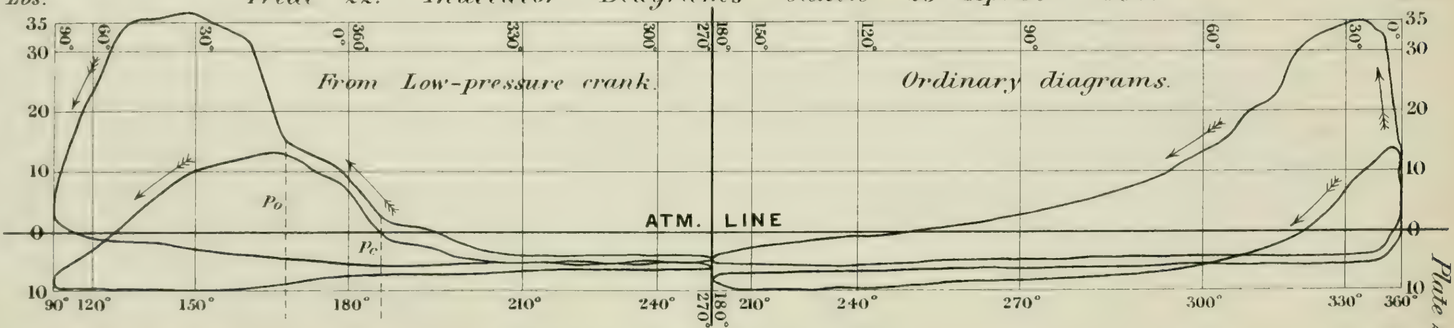
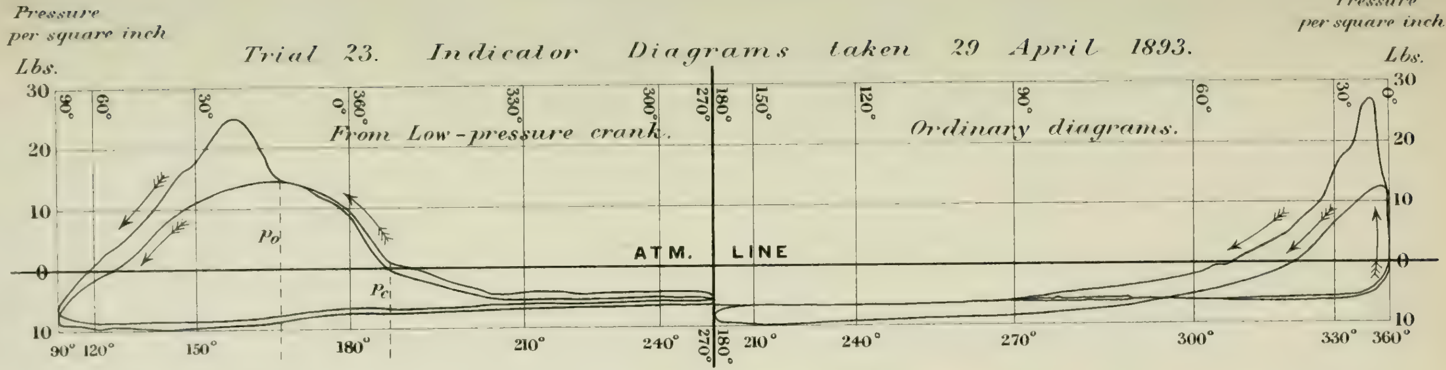


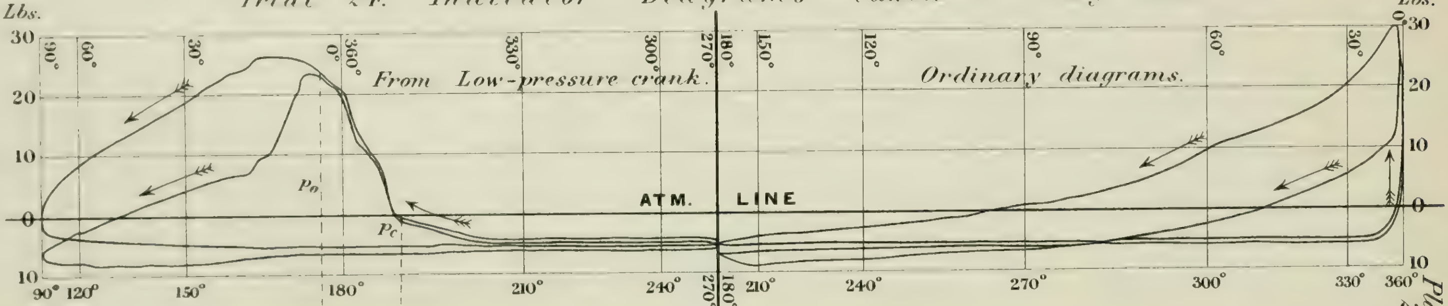
Plate 28.

INITIAL CONDENSATION.

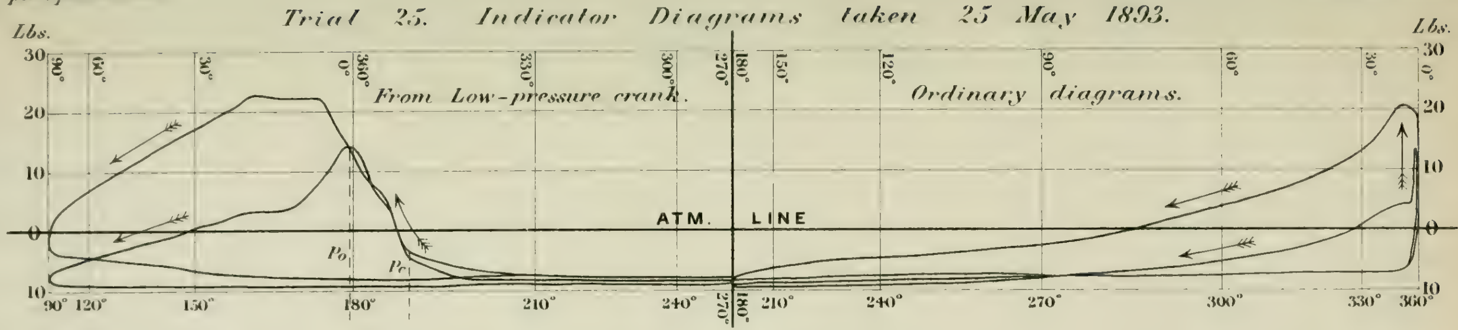
Trial 23. Indicator Diagrams taken 29 April 1893.



Trial 24. Indicator Diagrams taken 15 May 1893.



INITIAL CONDENSATION.



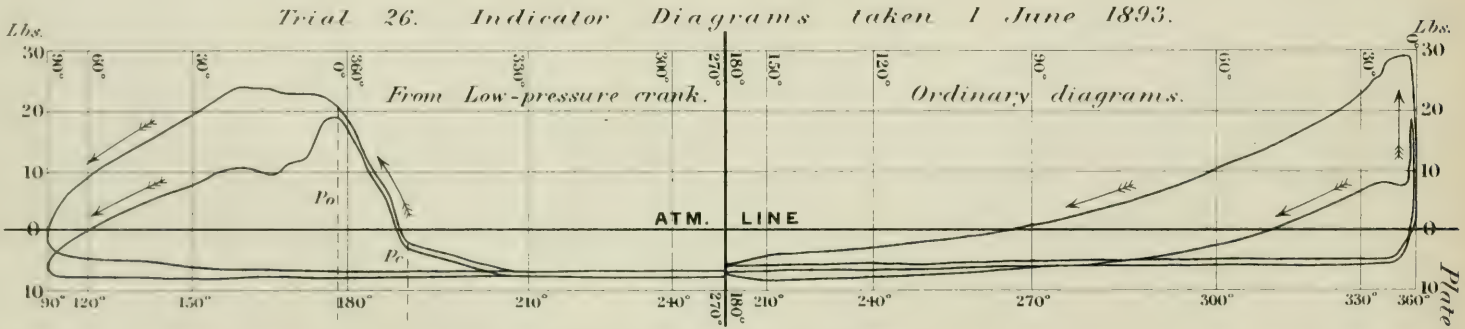


Plate 30.

INITIAL CONDENSATION.

Condensation Temperature Curves, combined with Indicator Diagrams.

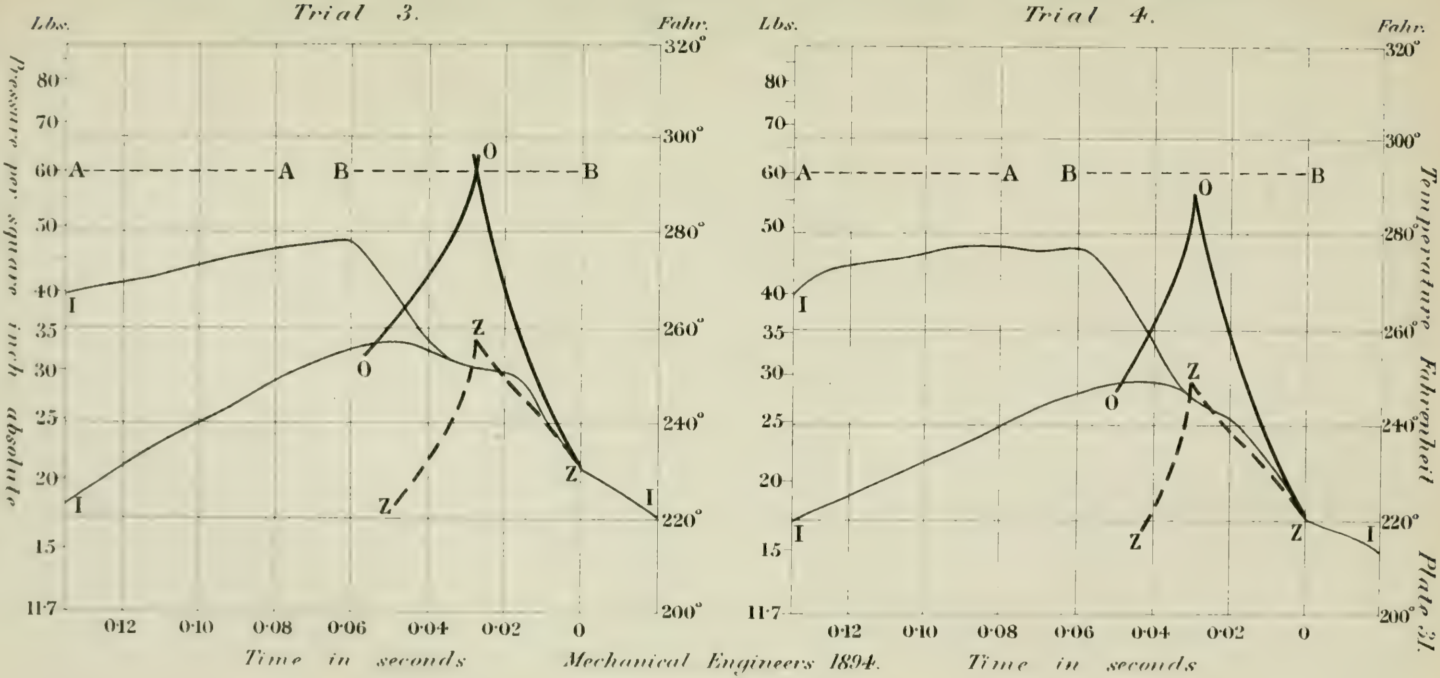


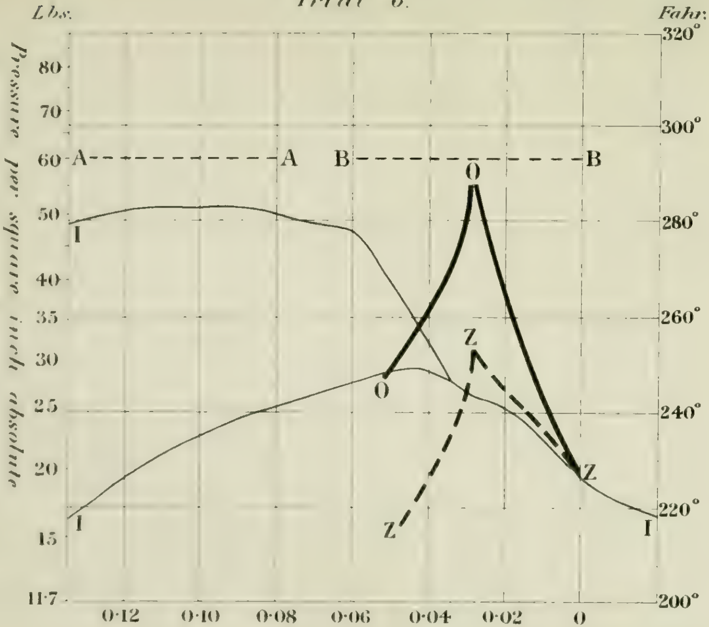
Plate 31.

INITIAL CONDENSATION.

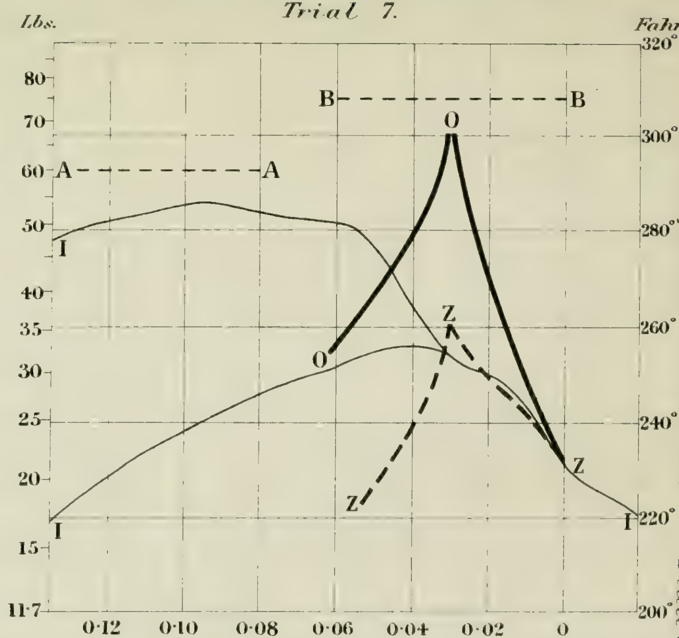
Plate 32.

Condensation Temperature Curves, combined with Indicator Diagrams.

Trial 6.



Trial 7.

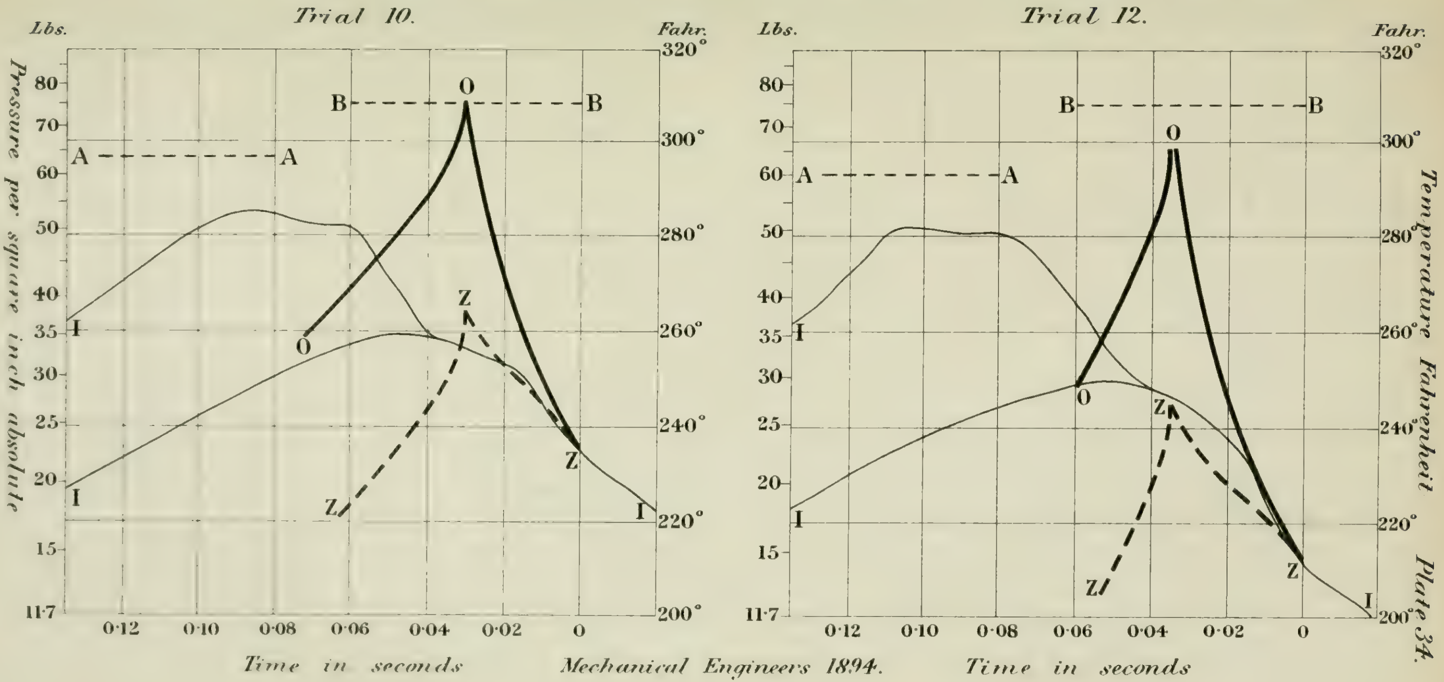


Mechanical Engineers 1894.

Plate 32.

INITIAL CONDENSATION.

Condensation Temperature Curves, combined with Indicator Diagrams.

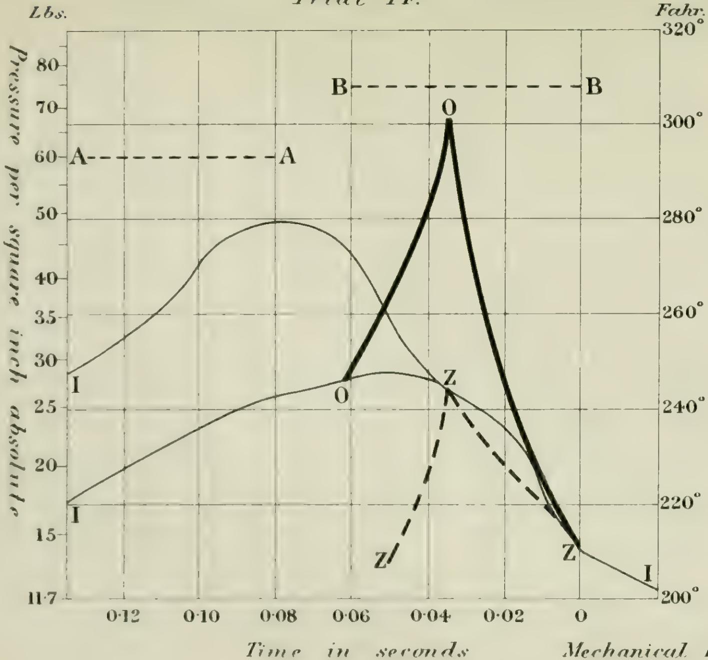


Mechanical Engineers 1894.

INITIAL CONDENSATION.

Condensation Temperature Curves, combined with Indicator Diagrams.

Trial 14.



Trial 15.

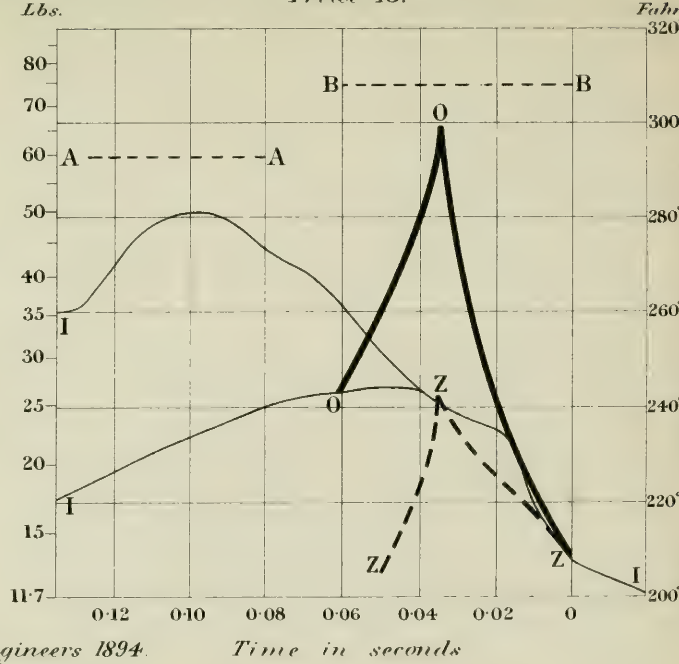
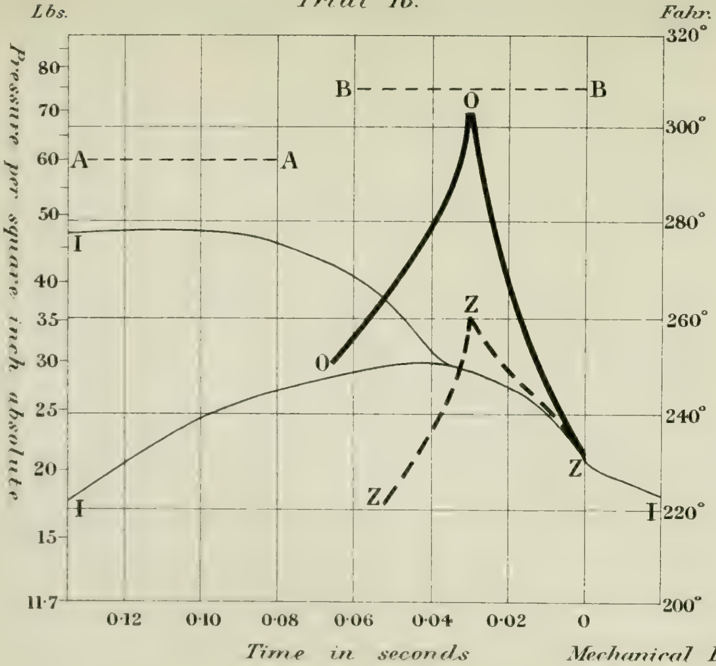


Plate 35.

INITIAL CONDENSATION.

Condensation Temperature Curves, combined with Indicator Diagrams.

Trial 16.



Trial 17.

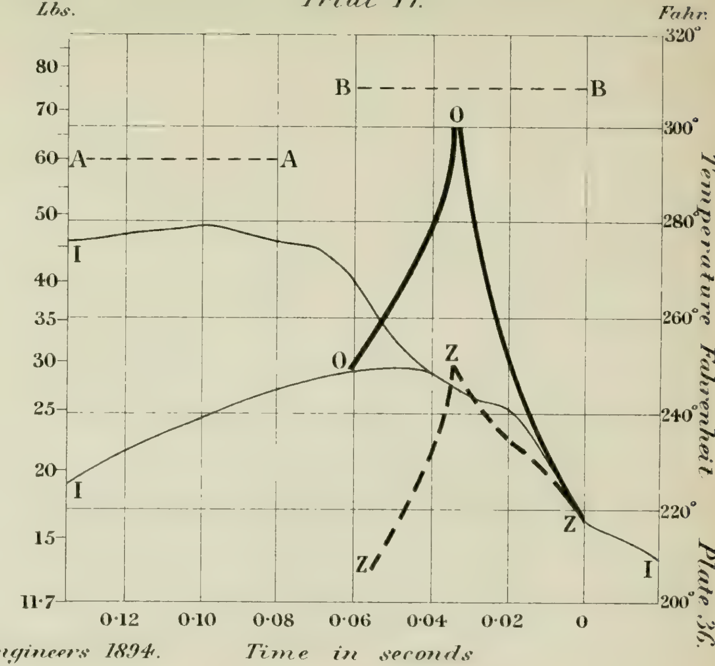


Plate 36.

Mechanical Engineers 1894.

INITIAL CONDENSATION.

Condensation Temperature Curves, combined with Indicator Diagrams.

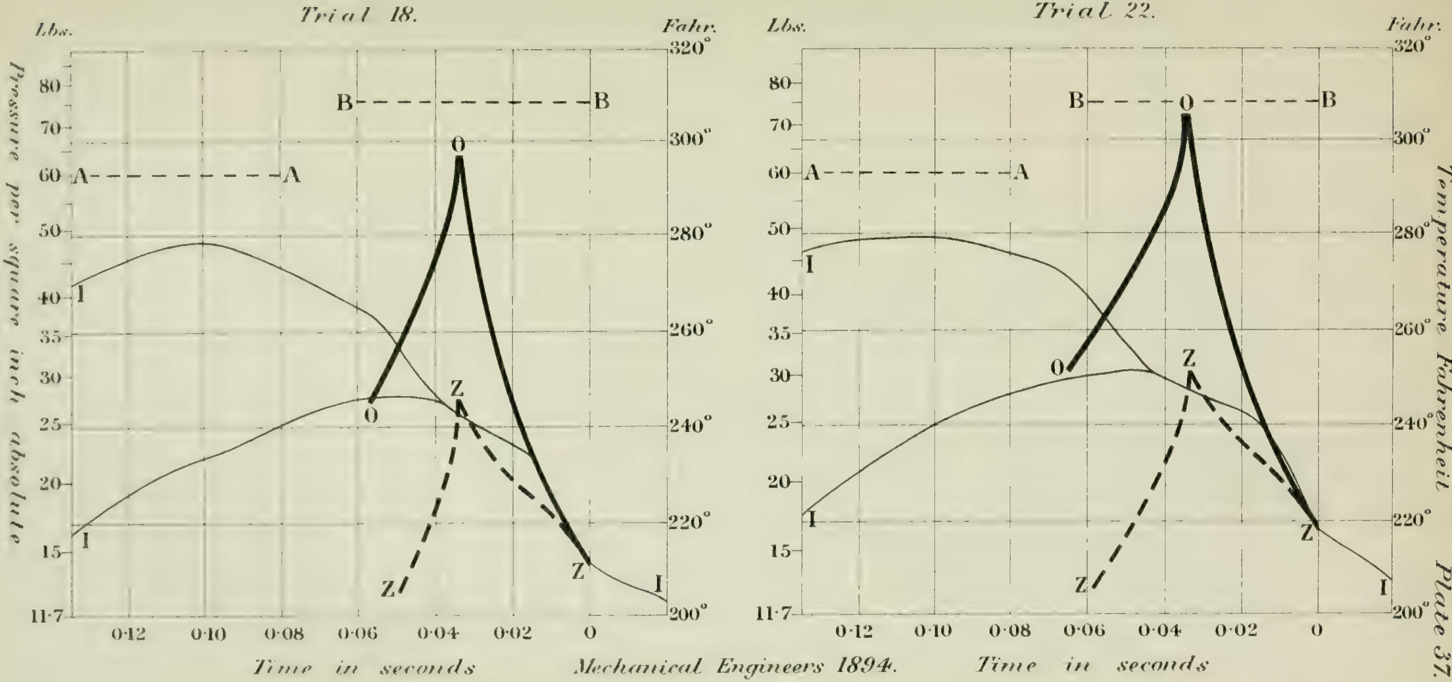
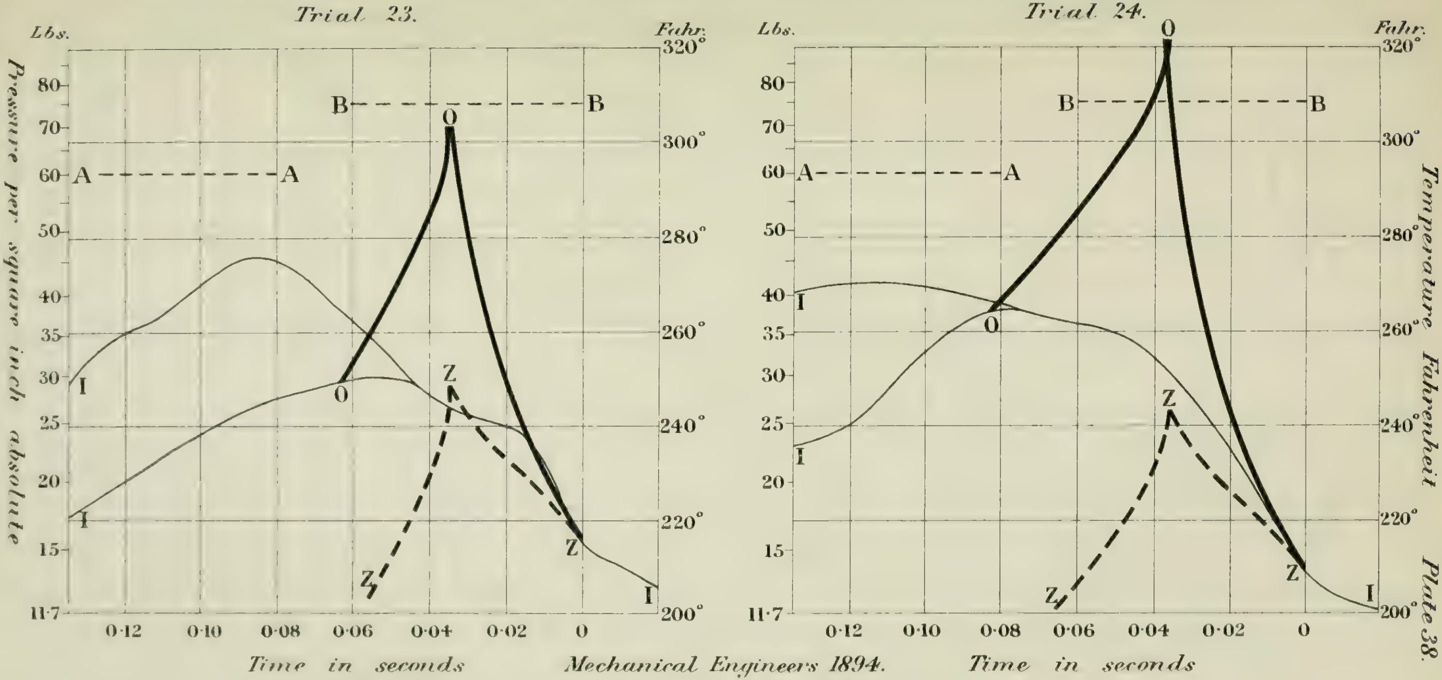


Plate 37.

INITIAL CONDENSATION.

Condensation Temperature Curves, combined with Indicator Diagrams.



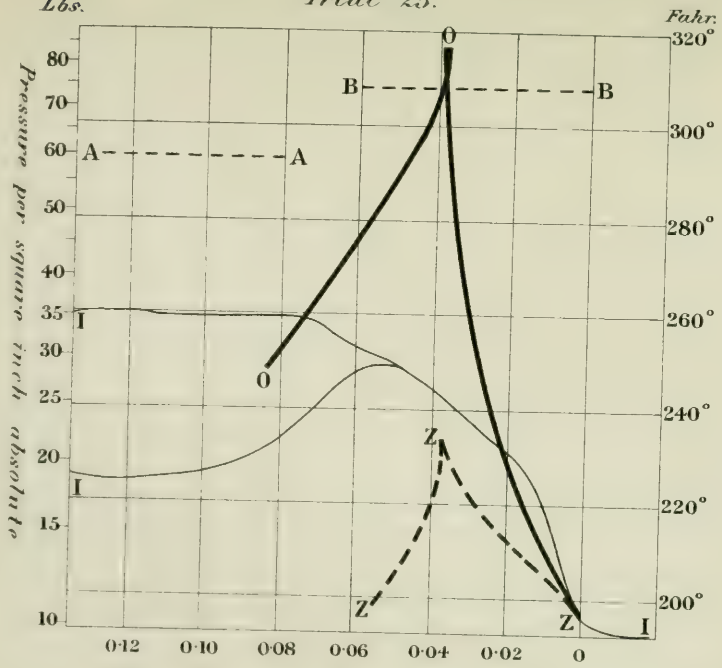
Mechanical Engineers 1894.

INITIAL CONDENSATION.

Plate 39.

Condensation Temperature Curves, combined with Indicator Diagrams.

Trial 25.



Trial 26.

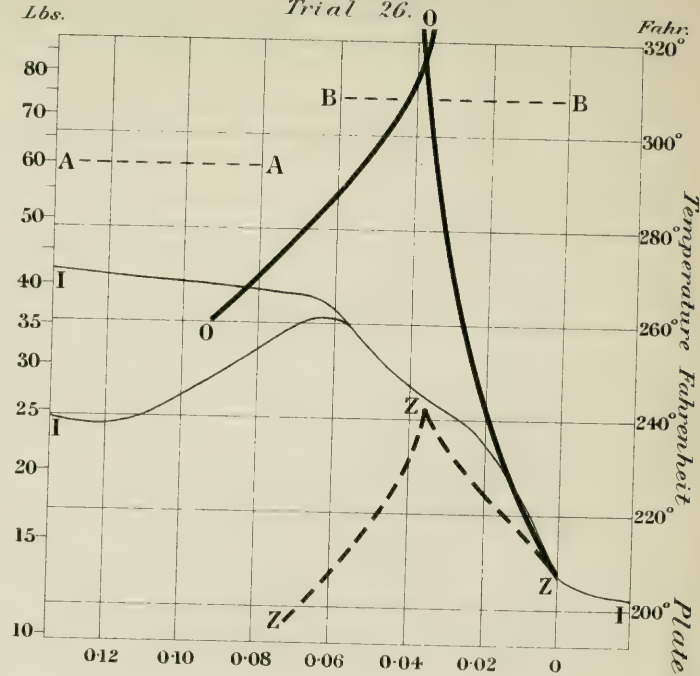
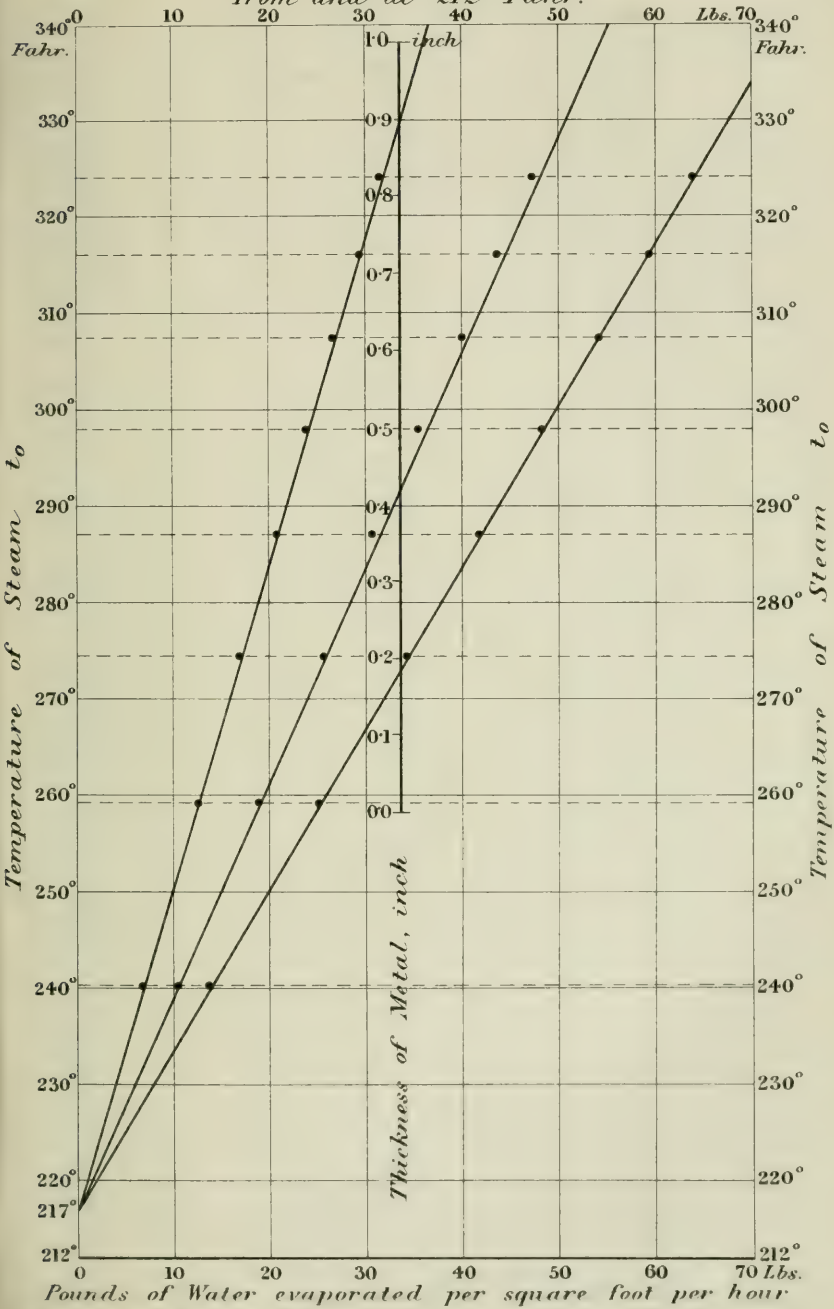


Plate 39.

INITIAL CONDENSATION.

Plate 40.

Transmission of Heat from Steam-Jacket through Cast-Iron Cylinder-Liners of varying thickness.



Mechanical Engineers 1894.

Fig. 1. *Variations of Output during a Year.*

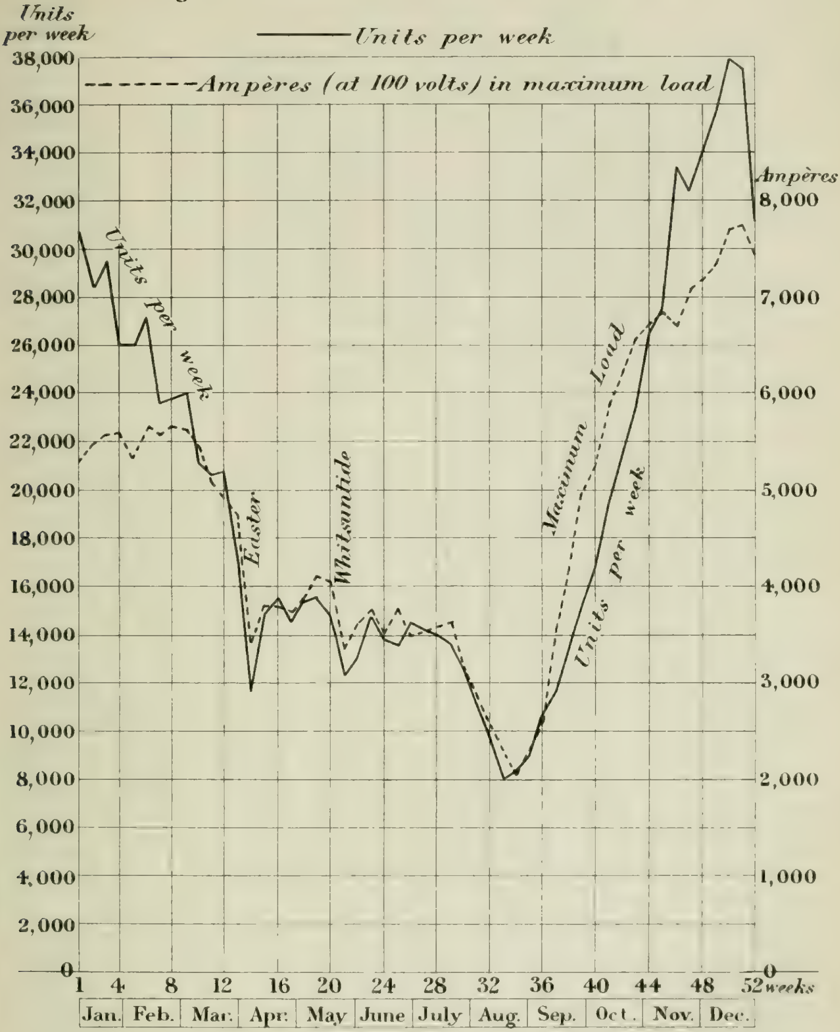
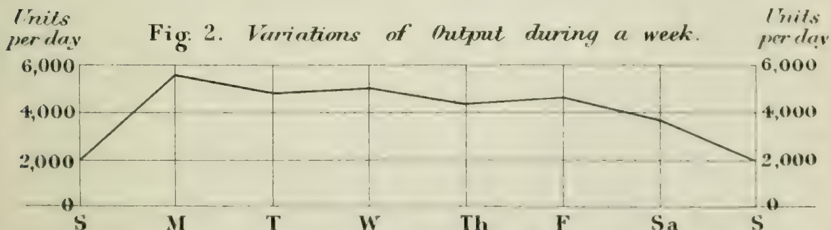
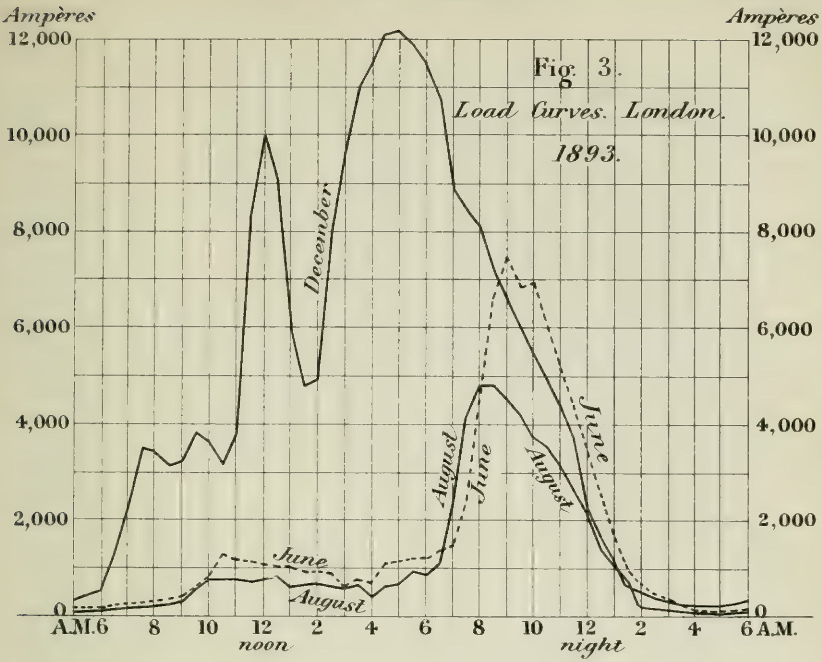


Fig. 2. *Variations of Output during a week.*



ELECTRIC LIGHTING.



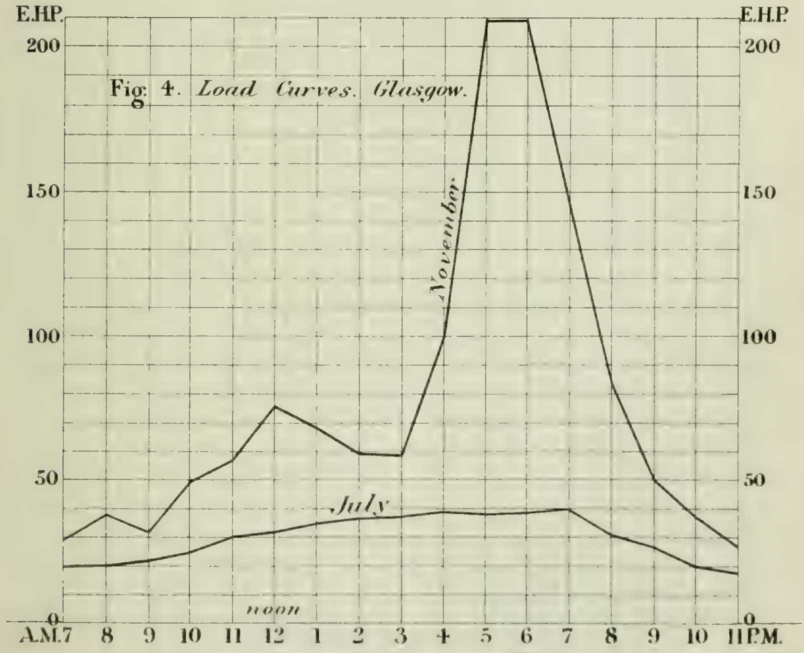


Diagram of Load Factors.

Fig. 5. *Millbank Street Station, London. 16 Nov. 1893.*

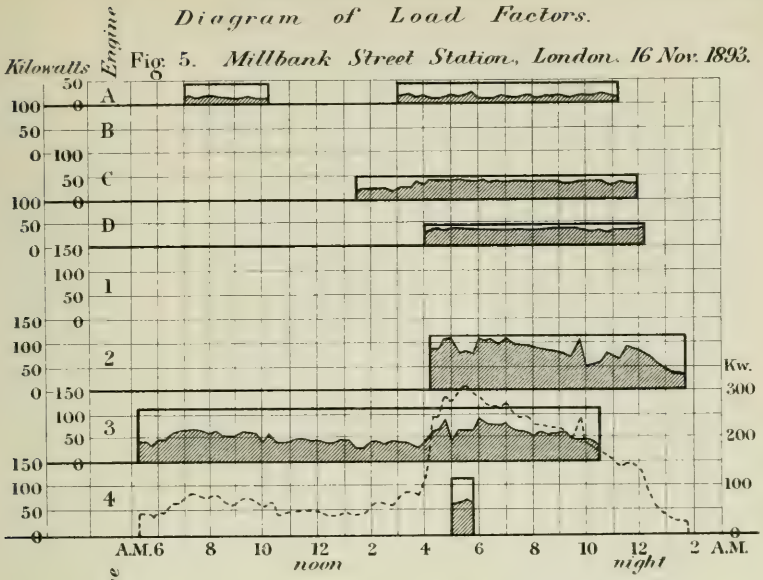
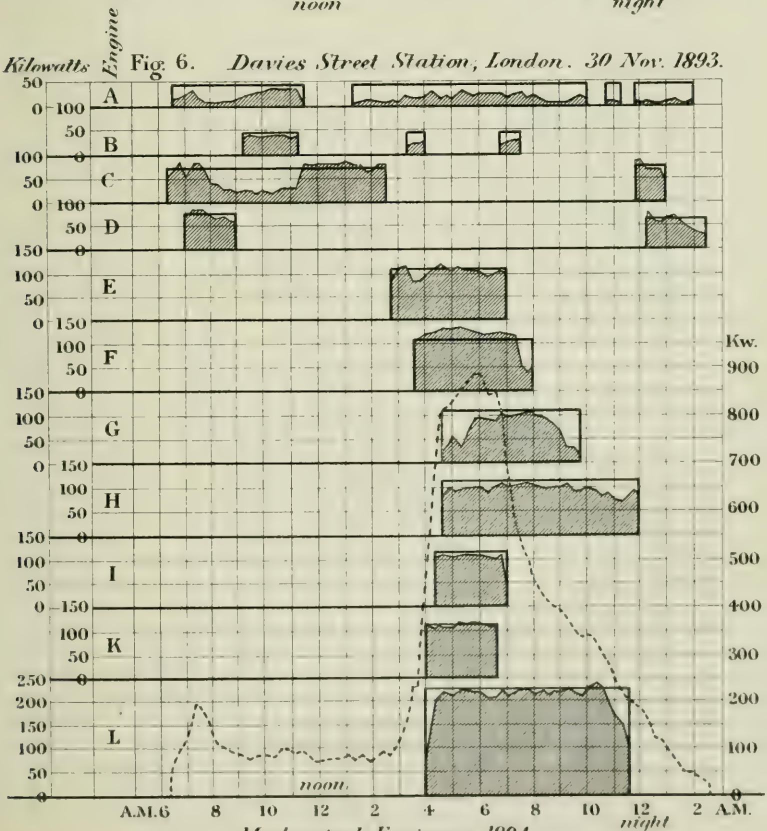
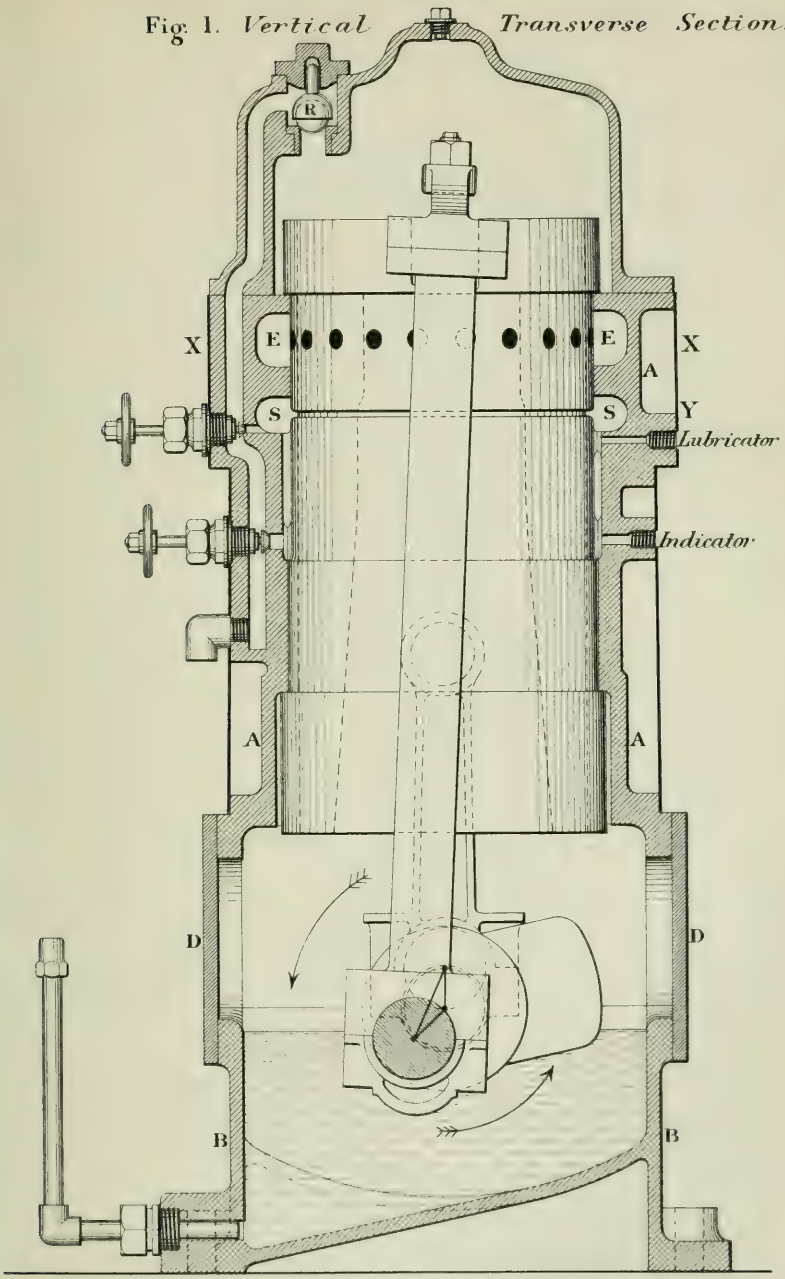


Fig. 6. *Davies Street Station, London. 30 Nov. 1893.*



HIGH-SPEED ENGINE. *Plate 44.*

Fig. 1. *Vertical Transverse Section.*

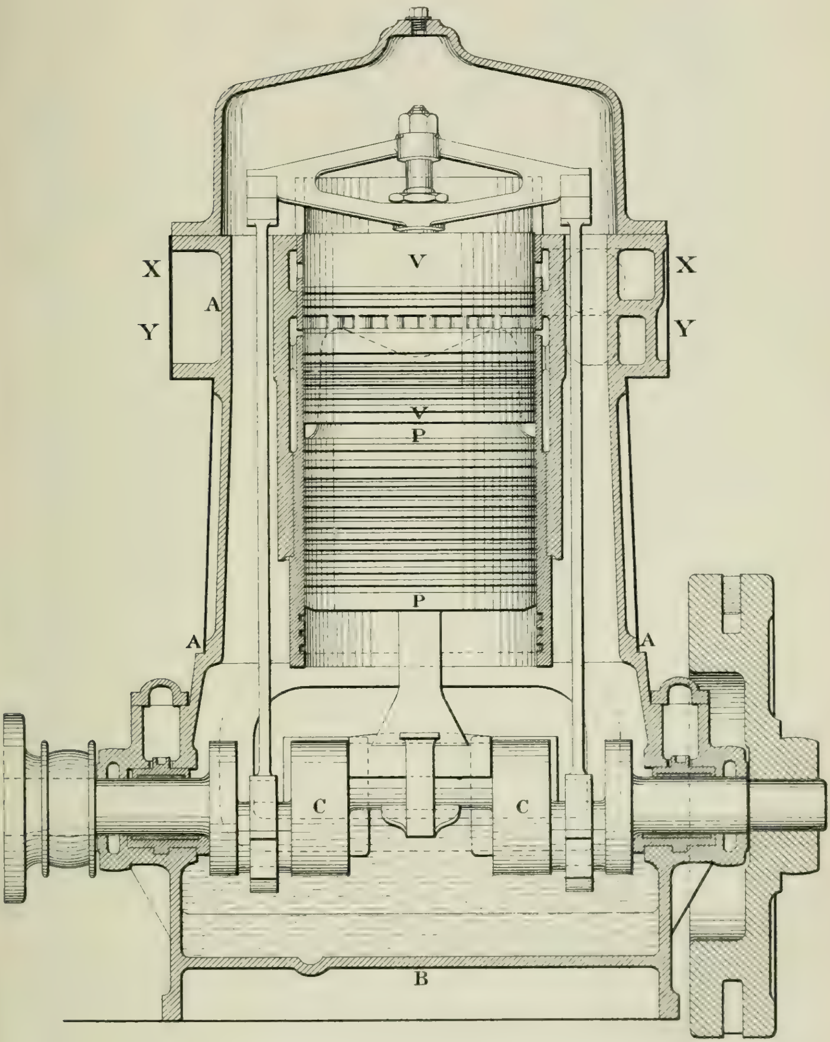


Mechanical Engineers 1894.

Scale 1/8th

0 5 10 15 20 25 Inches

Fig. 2. *Vertical Longitudinal Section.*



Scale 1/10th

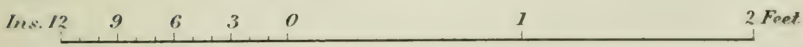


Fig. 3. *Sectional Plan through annular Exhaust channel, at XX, Figs. 1 and 2.*

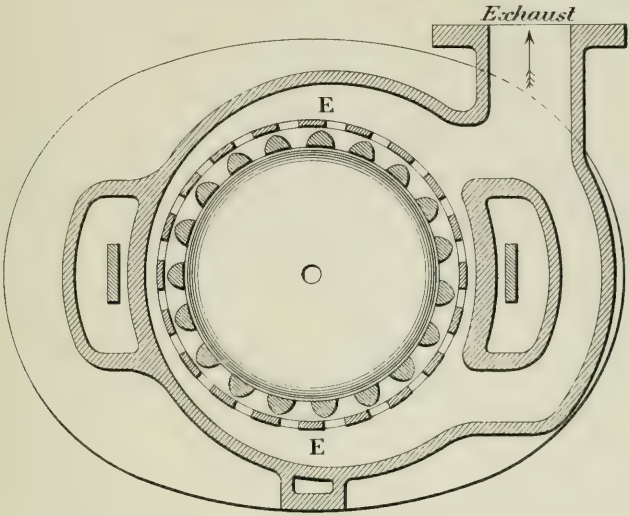
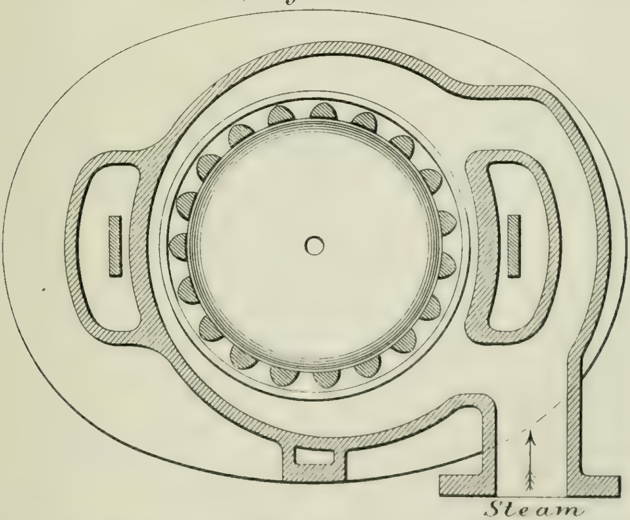


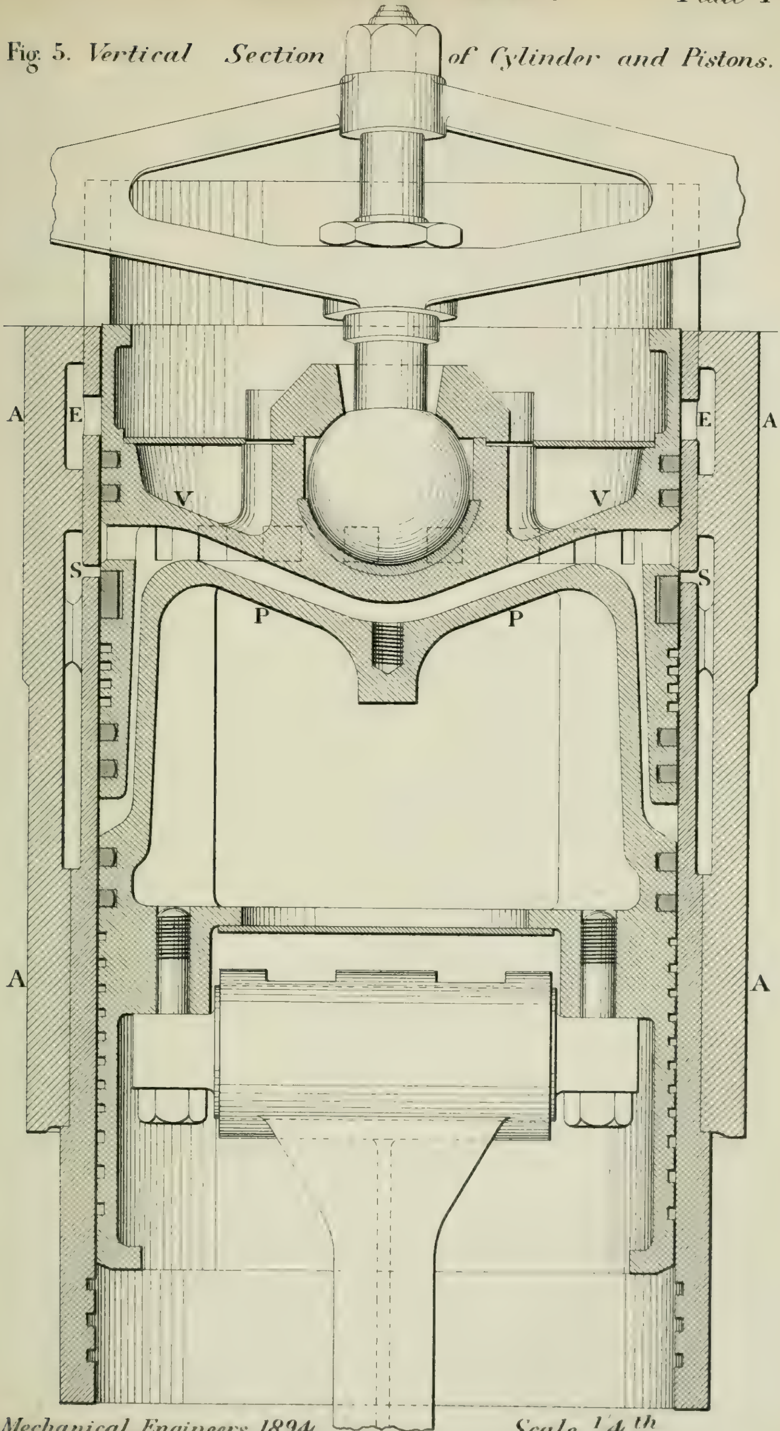
Fig. 4. *Sectional Plan through annular Steam channel, at YY, Figs. 1 and 2.*



Mechanical Engineers 1894. *Scale 1/8th*

0 5 10 15 20 Inches

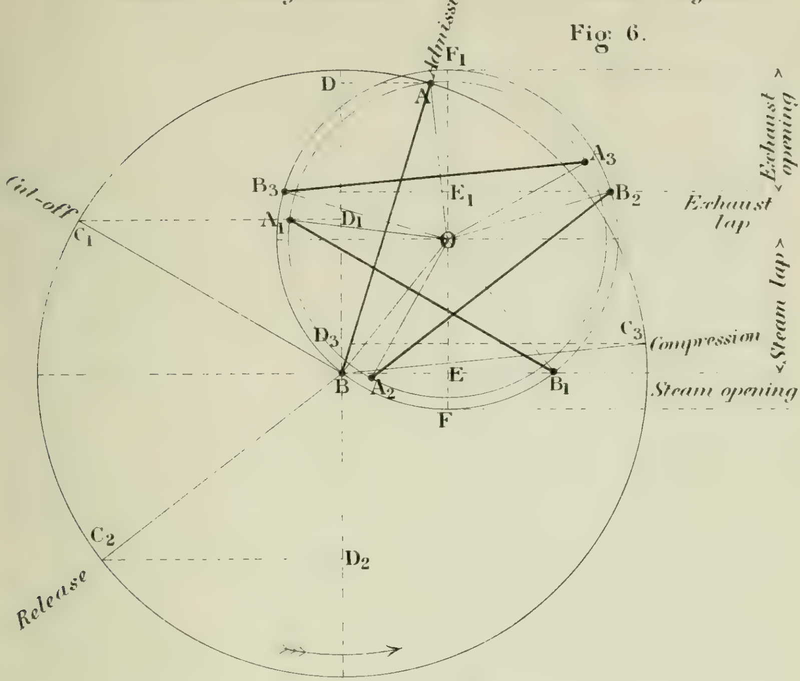
Fig. 5. *Vertical Section of Cylinder and Pistons.*



 Scale 1/4th

Valve Diagrams for 12-inch Engine.

Fig: 6.



Half full size.

Fig: 7.

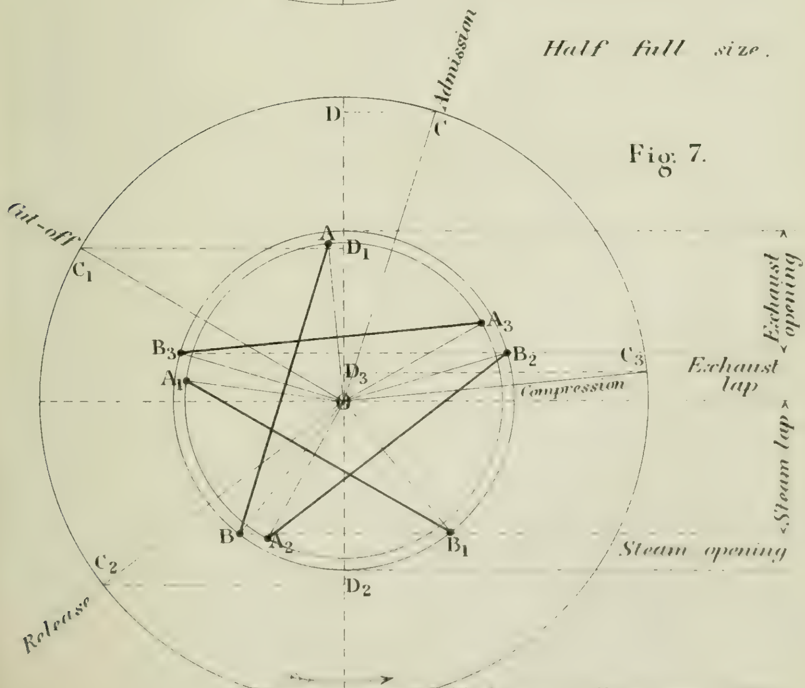
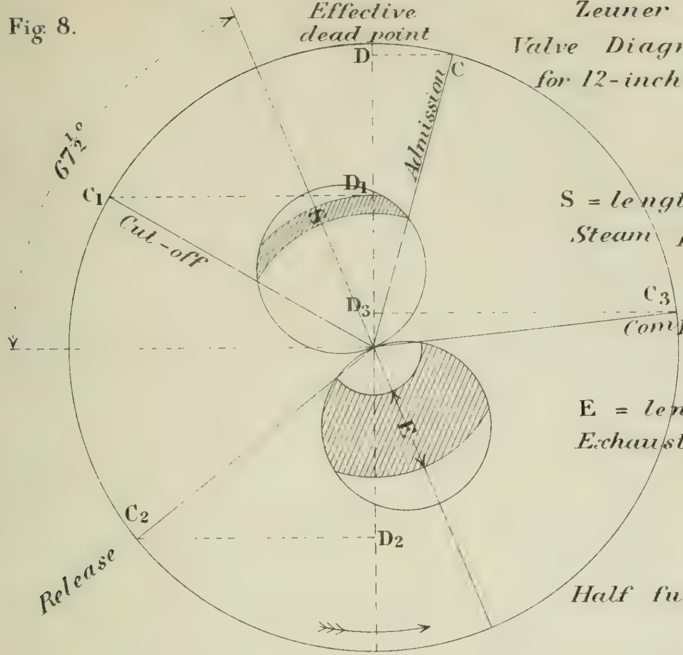


Fig. 8.

Zeuner Valve Diagrams for 12-inch Engine.

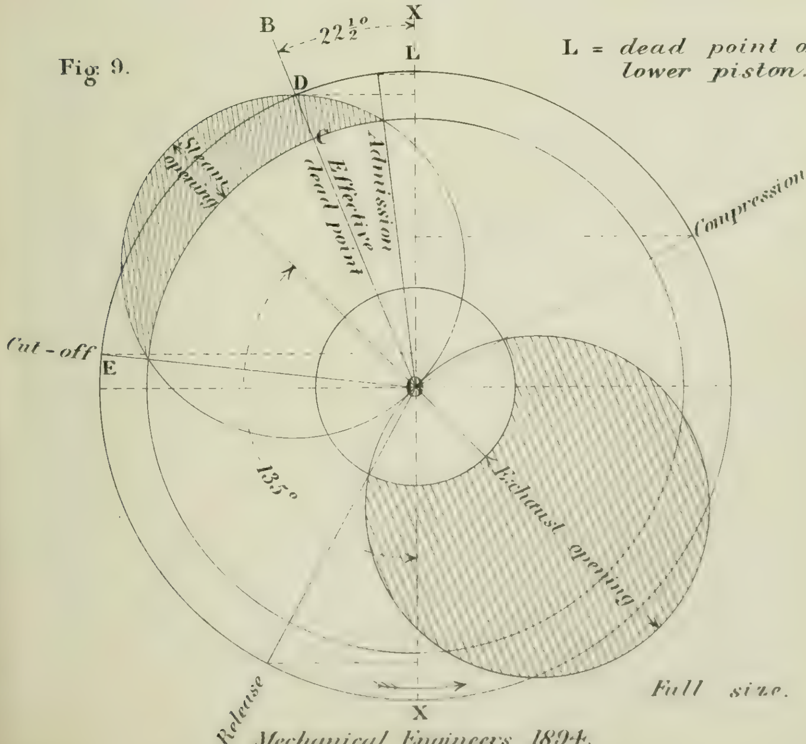


S = *length of Steam port.*

E = *length of Exhaust port.*

Half full size.

Fig. 9.



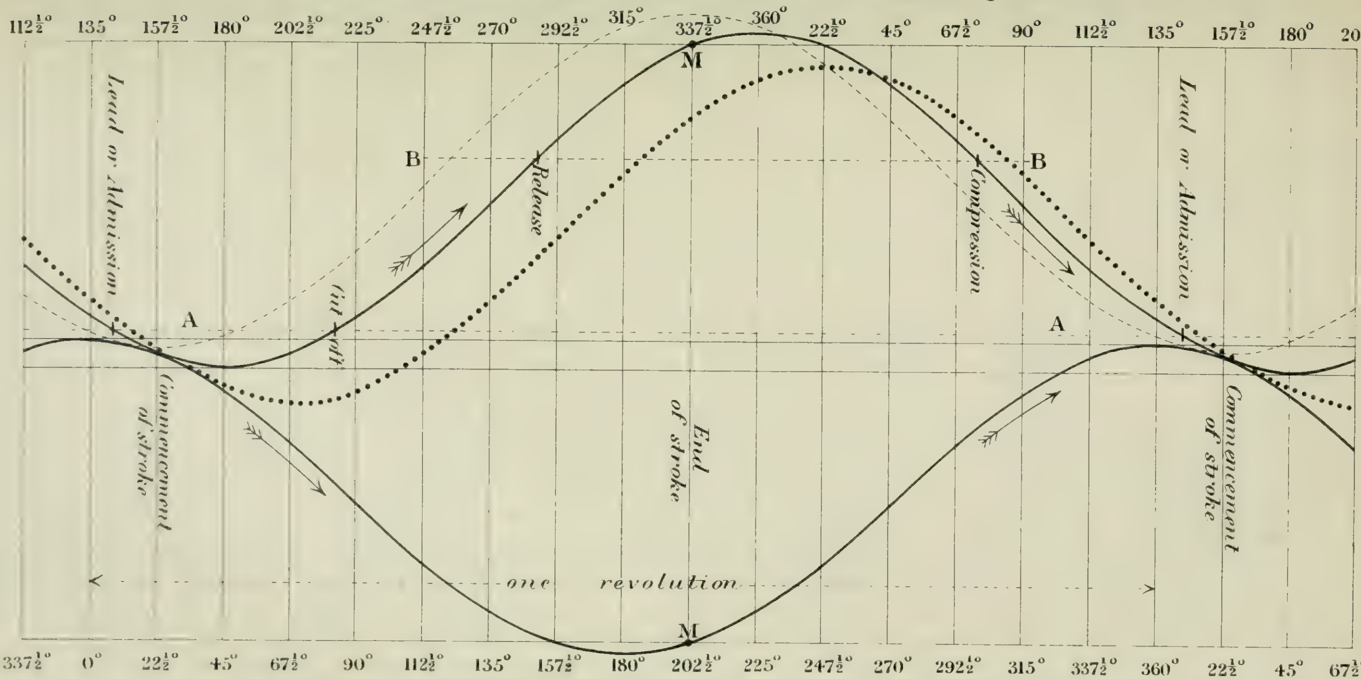
L = *dead point of lower piston.*

Full size.

HIGH-SPEED ENGINE.

Fig. 10. *Effective stroke of Pistons.*

Angular positions of upper-piston crank-pins.



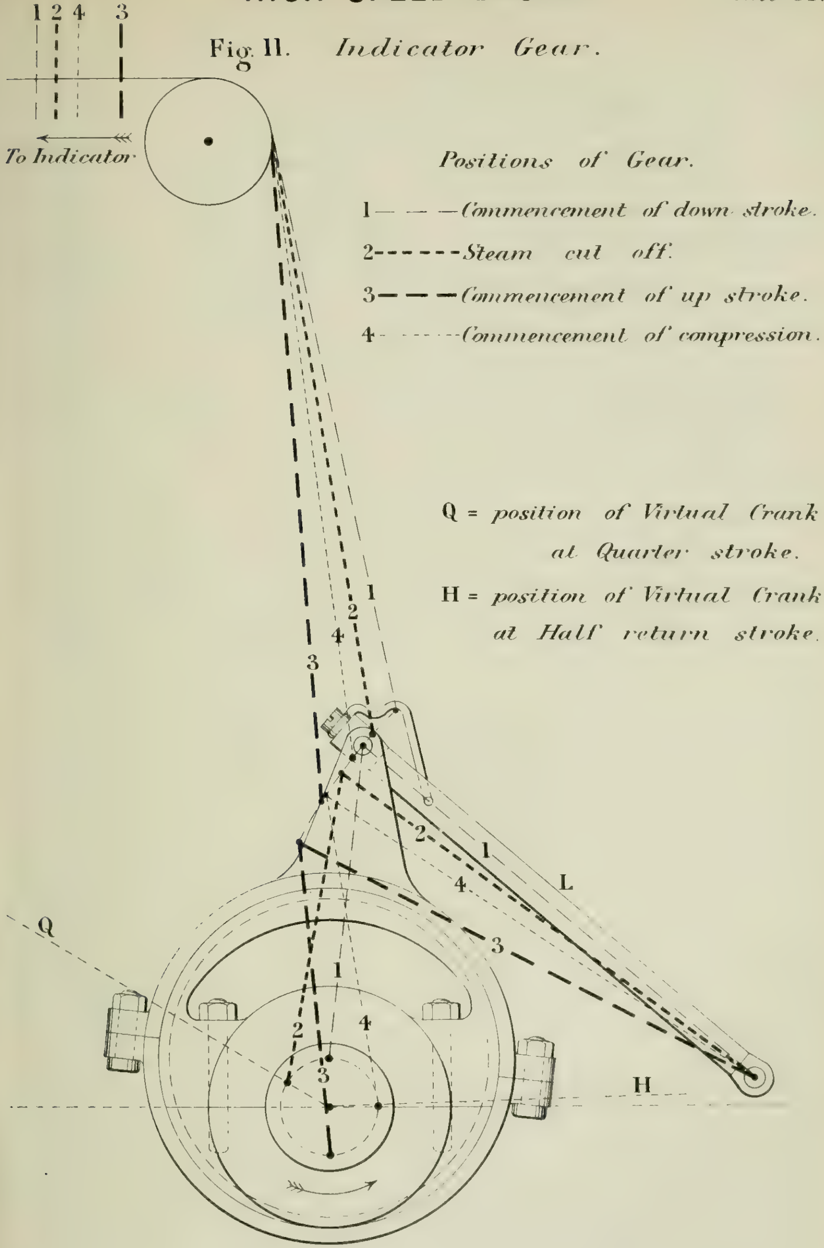
Angular positions of lower-piston crank-pin.

Mechanical Engineers 1894.

Half full size.

Plate 50.

Fig. 11. *Indicator Gear.*



Mechanical Engineers 1894. *Scale 1/3rd*

1 0 1 2 3 4 5 6 7 8 Inches

Fig. 12. *Indicator Diagram from 8-inch Engine.*

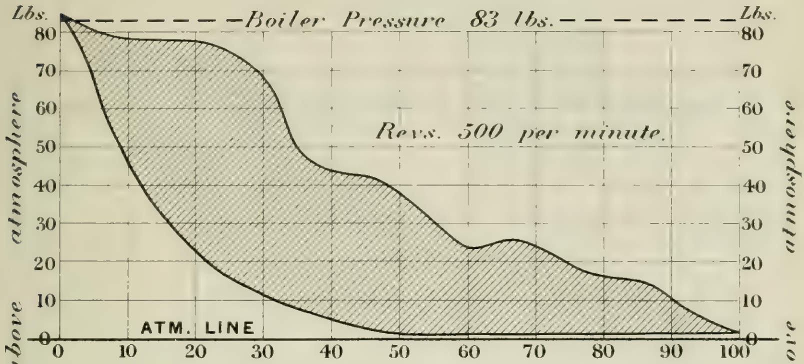


Fig. 13. *Indicator Diagram from 12-inch Engine.*

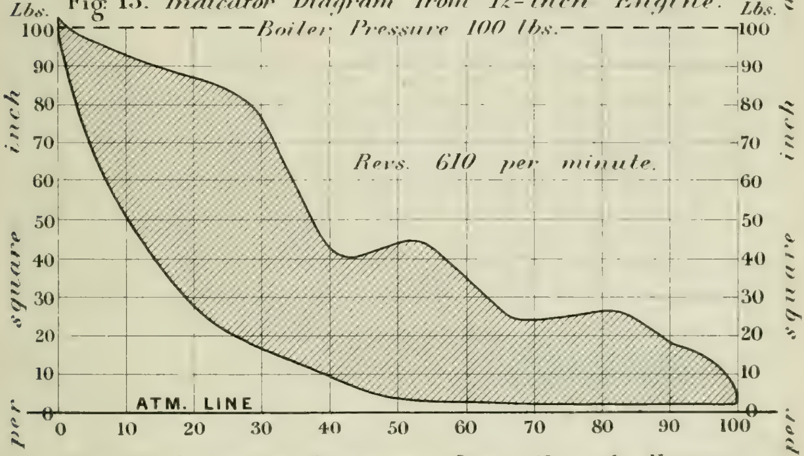
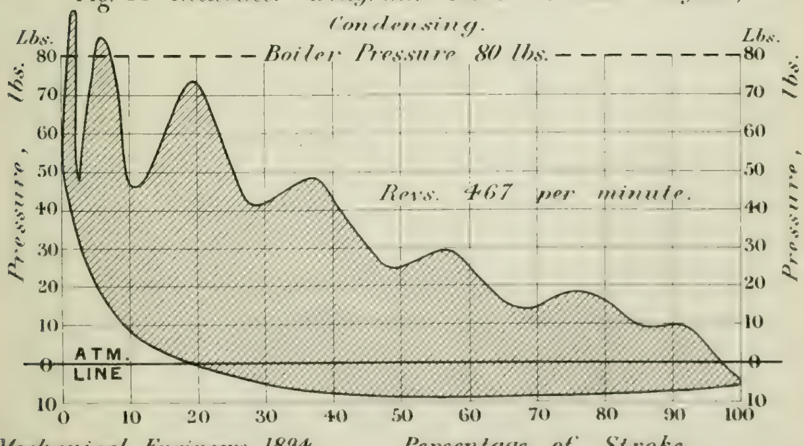


Fig. 14. *Indicator Diagram from 12-inch Engine, Condensing.*



Perry Indicator. Scale half size.

Fig. 15. *Longitudinal Section.*

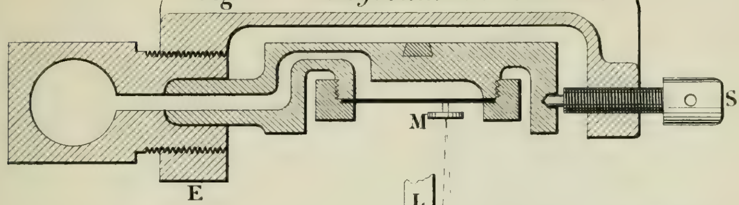
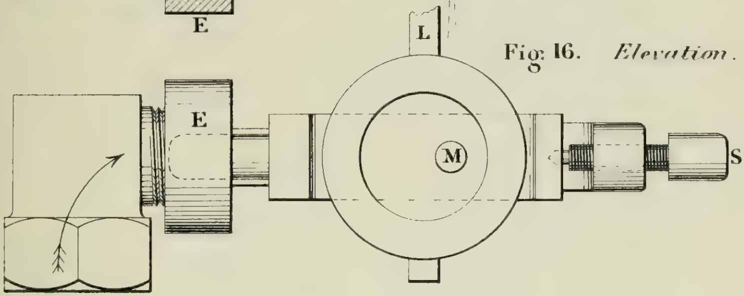


Fig. 16. *Elevation.*



Indicator Diagrams from 6-inch Engine.

Fig. 17. *Boiler Pressure 98 lbs.*
Revs. 484 per minute.

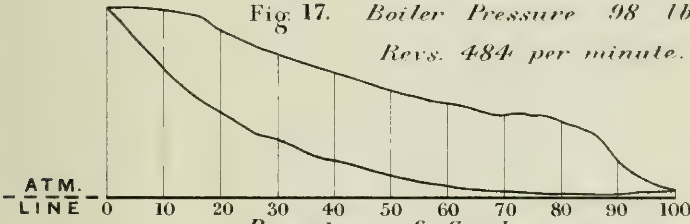


Fig. 18. *Boiler Pressure 100 lbs.*
Revs. 494 per minute.

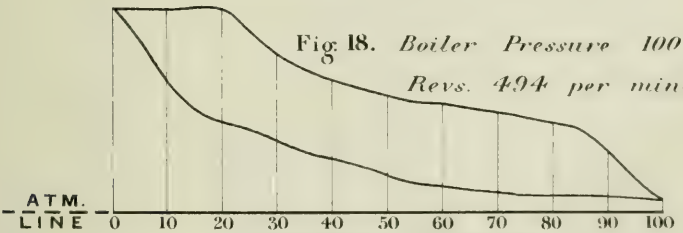
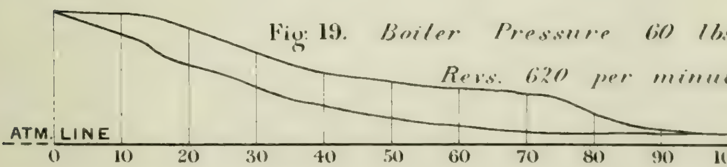
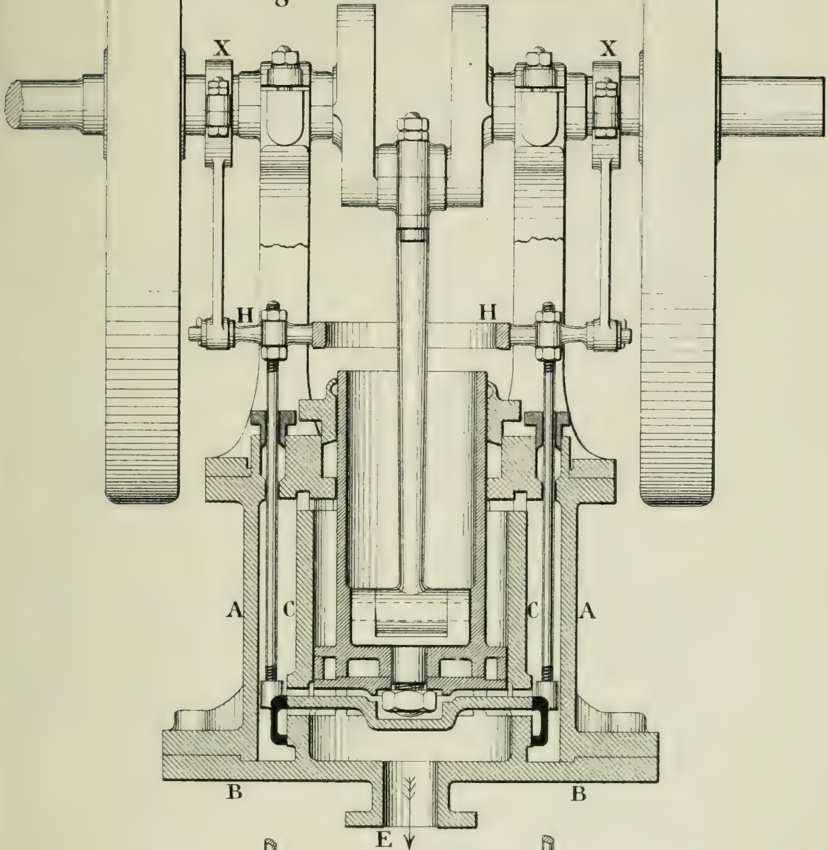


Fig. 19. *Boiler Pressure 60 lbs.*
Revs. 620 per minute.



Double-acting Engine with Circumferential Valve surrounding Cylinder.

Fig: 20. *Vertical Section.*



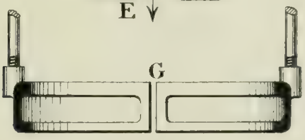


Fig: 21. *Vertical Section of Valve.*

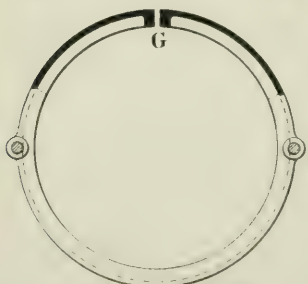


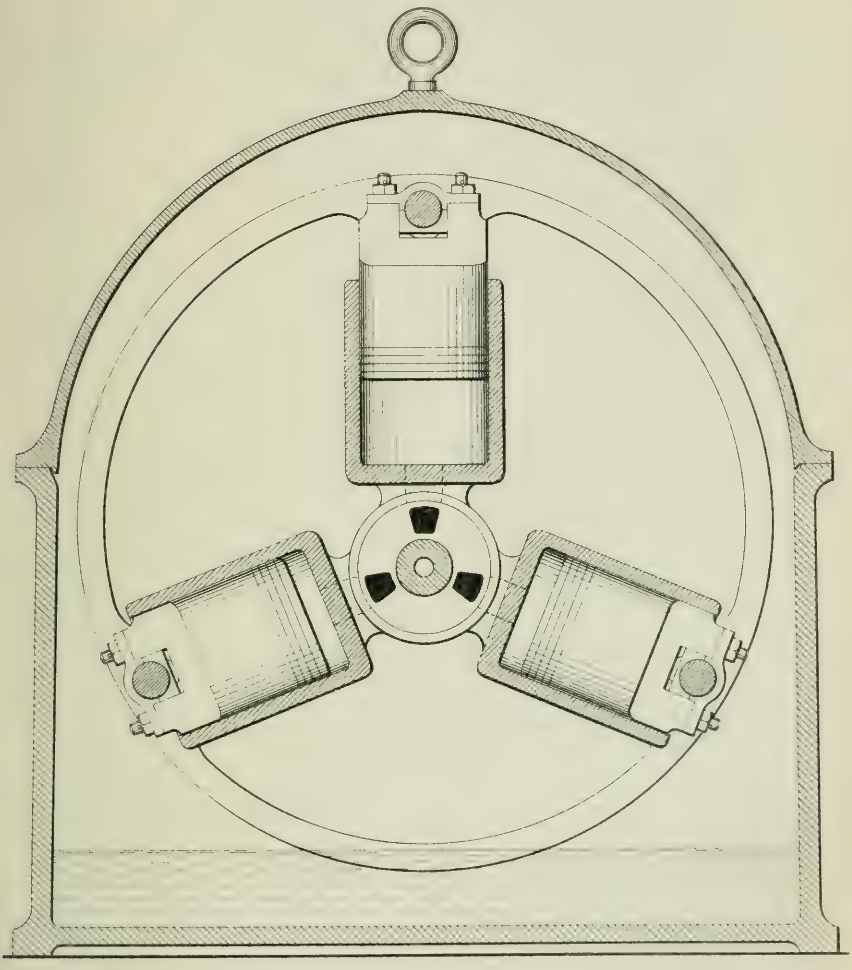
Fig: 22. *Plan of Valve.*

Scale 1/8th.

0 5 10 15 Inches

Fig. 23.

Revolving Engine.



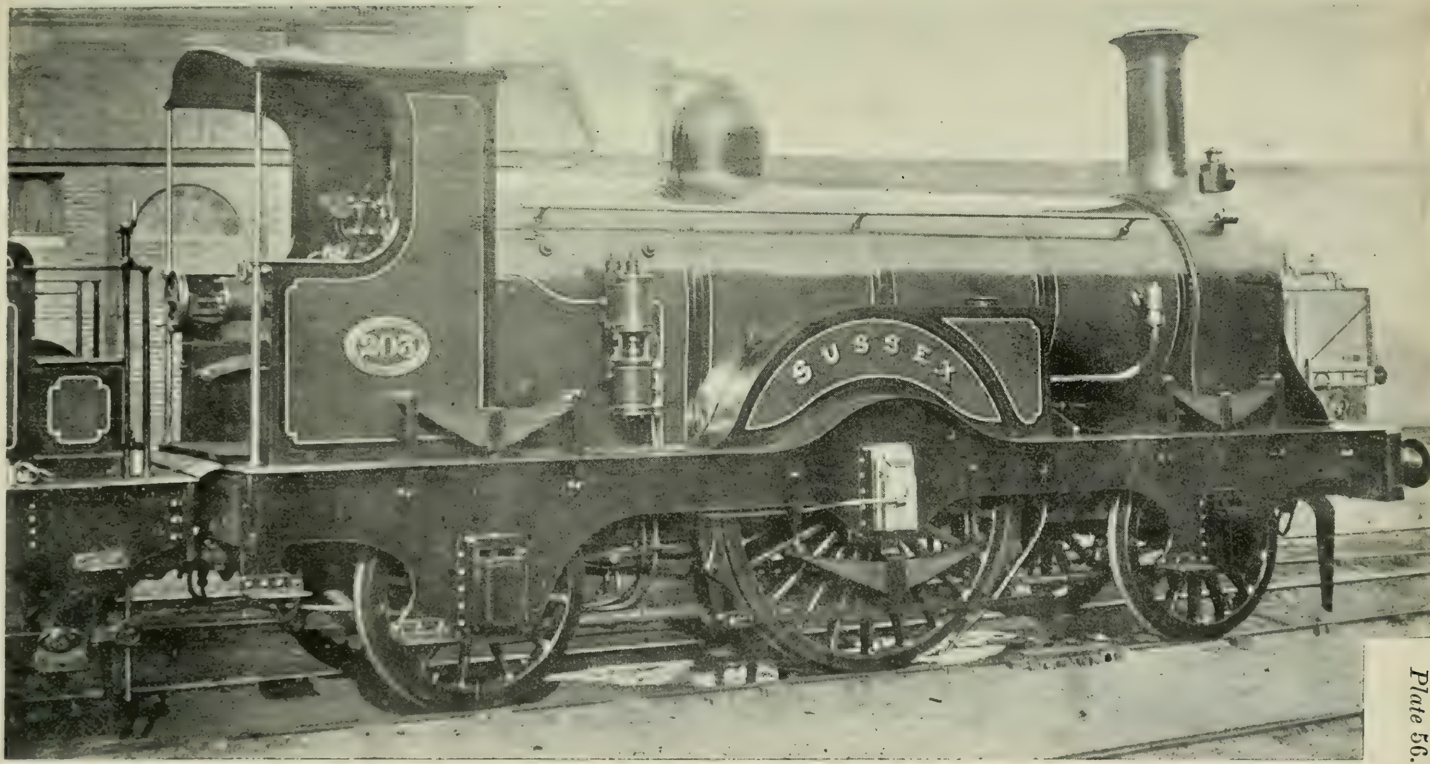
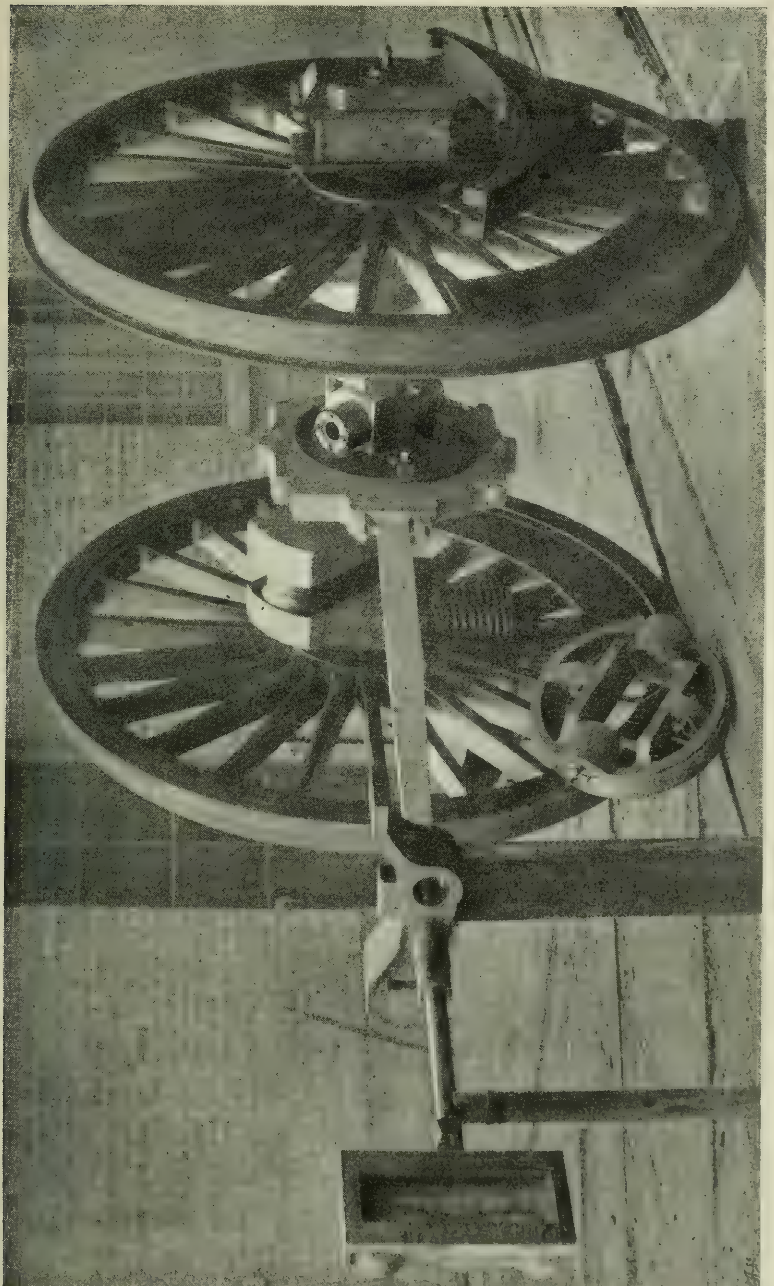


Plate 56.



FLUID-PRESSURE REVERSING GEAR.

Fig. 1. *Side Elevation.*

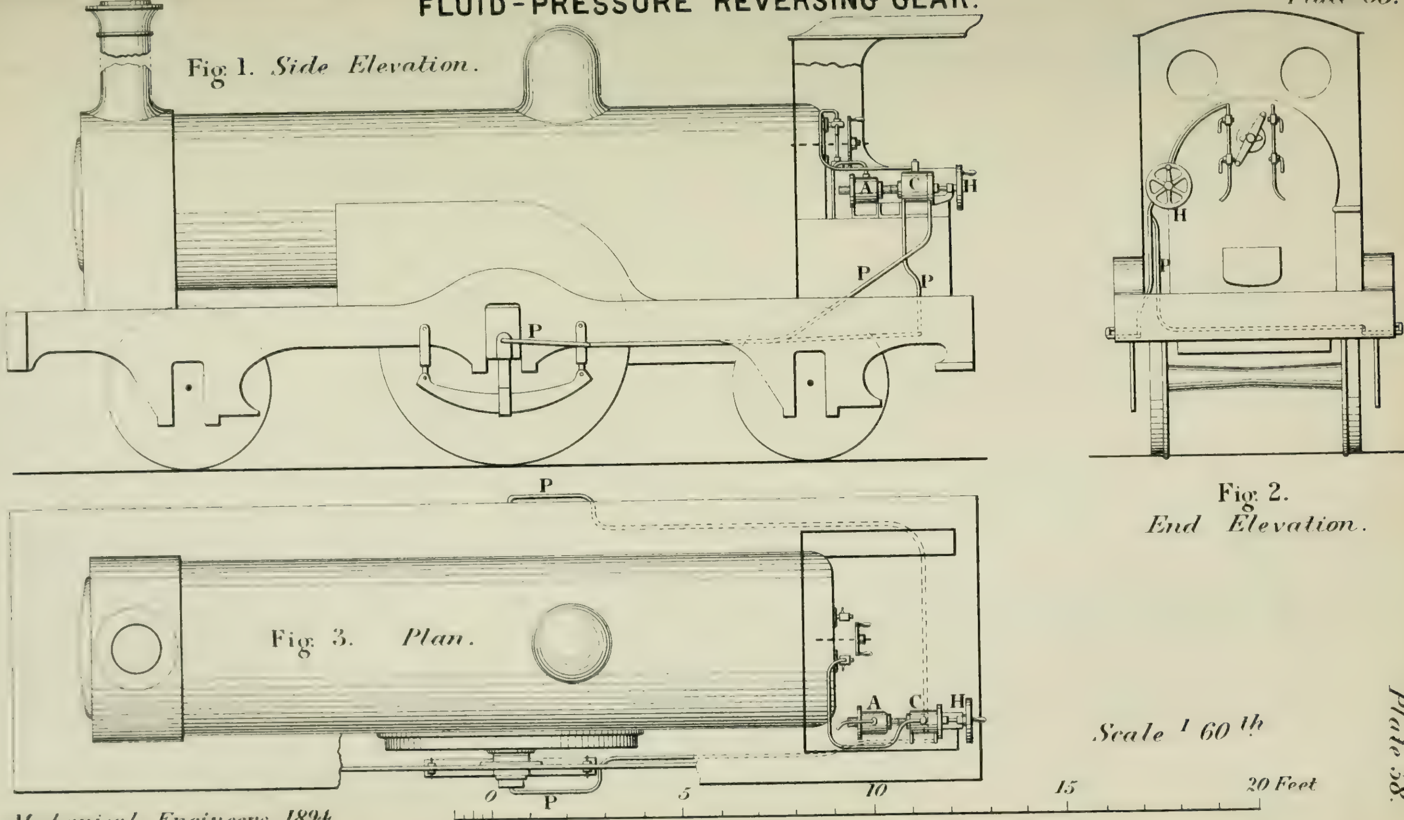


Fig. 2. *End Elevation.*

Fig. 3. *Plan.*

Scale 1/60 th

Plate 58.

FLUID-PRESSURE REVERSING GEAR.

Fig. 5. *Stuffing-box at end of axle.*

Scale 1/4th.

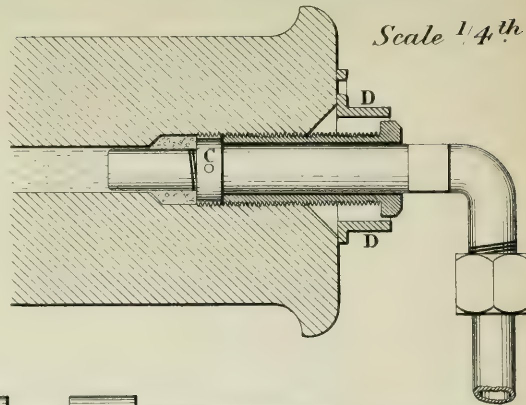
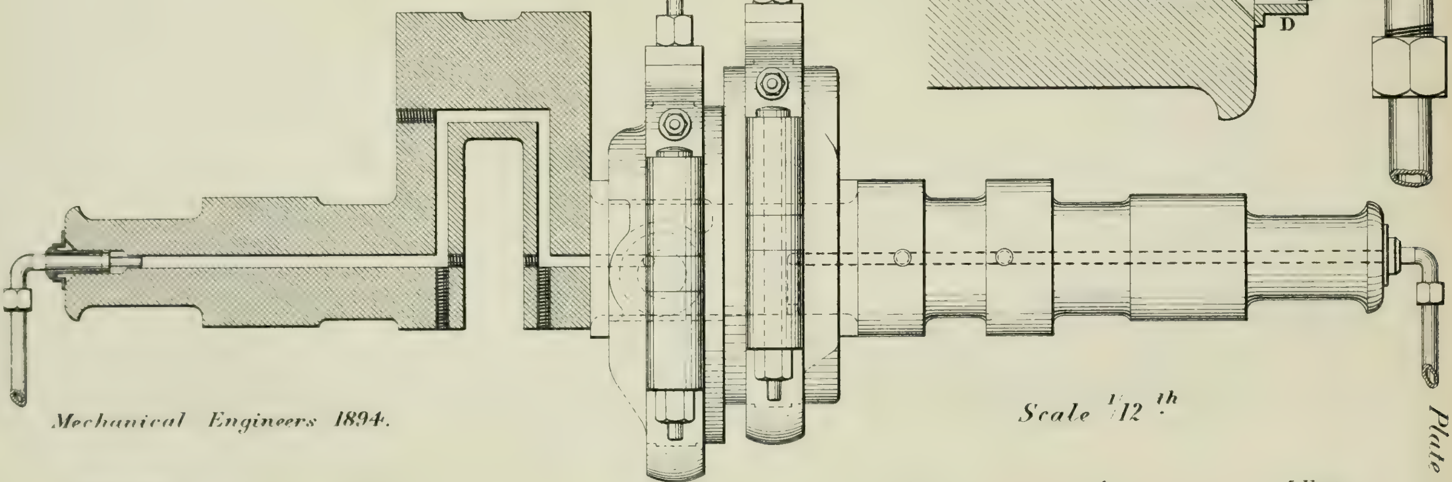


Fig. 4. *Plan of Crank Axle.*



Scale 1/12th.

Mechanical Engineers 1894.

Inches 12 6 0 1 2 3 4 5 *Feet*

Plate 59.

FLUID-PRESSURE REVERSING GEAR.

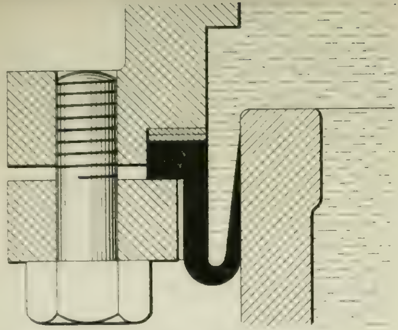


Fig. 9. *Metallic Packing. Full size.*

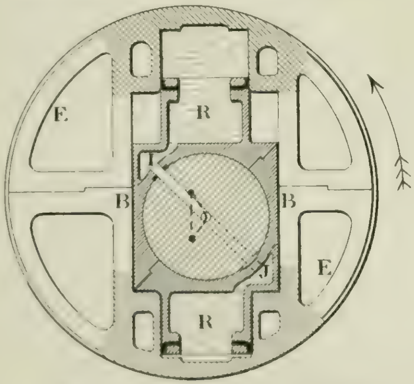


Fig. 6. *Transverse Section.*

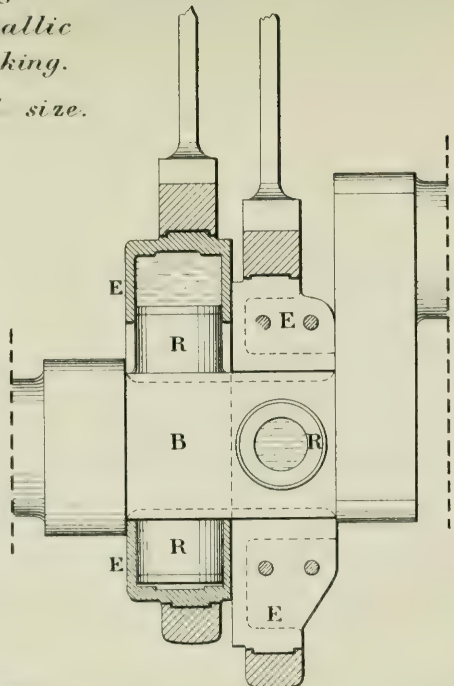


Fig. 7. *Plan.*

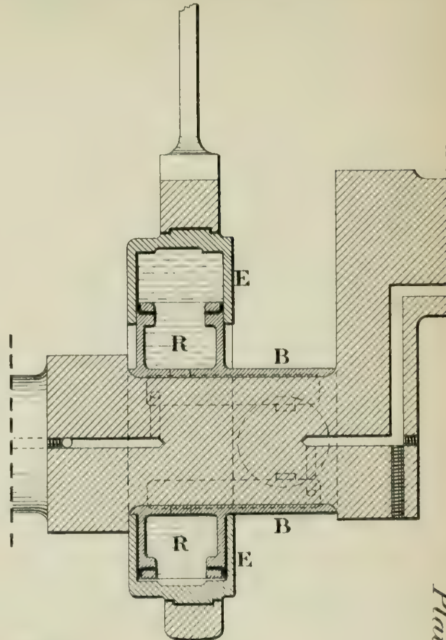


Fig. 8. *Longitudinal Section.*

Scale 1/12th

Inches 12 6 0 1 2 3 *Feet*

Mechanical Engineers 1894.

FLUID-PRESSURE REVERSING GEAR.

Fig. 10. *Front Elevation.*

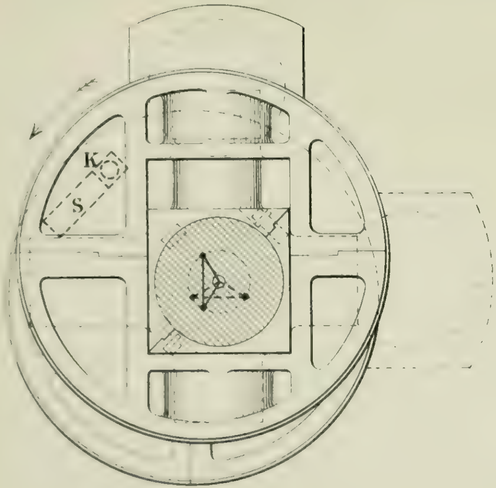


Fig. 11. *Longitudinal Section.*

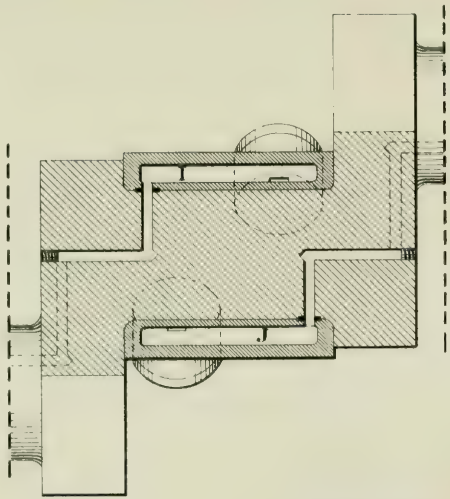
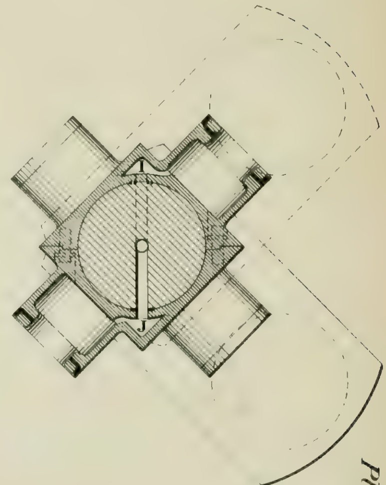


Fig. 12. *Transverse Section.*



Scale 1/12th

Plate 61.

FLUID-PRESSURE REVERSING GEAR.

Fig. 13. *Longitudinal Section of Reversing Cylinder.*

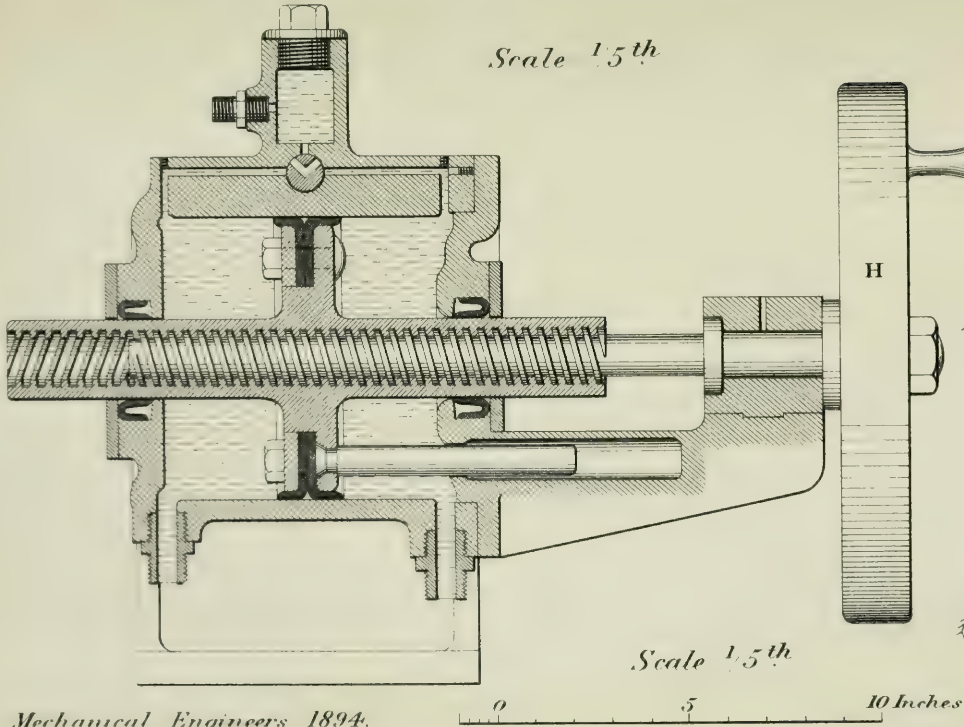


Fig. 14. *Link Gear.*

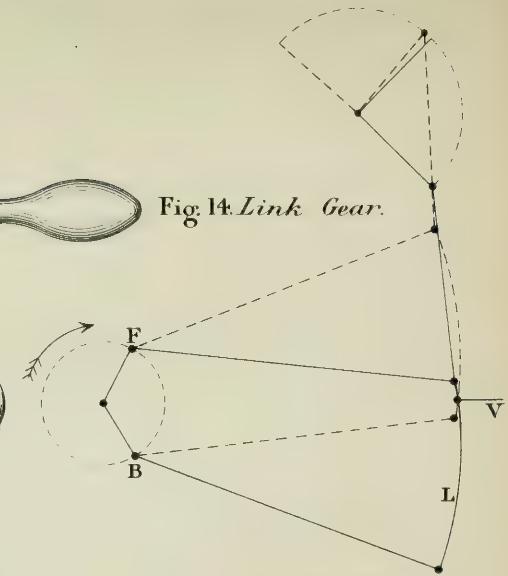
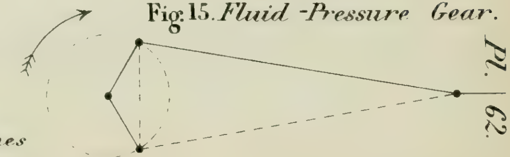


Fig. 15. *Fluid-Pressure Gear.*



FLUID-PRESSURE REVERSING GEAR.

Link Gear of Marine Engines.

Fig. 16. *End Elevation.*

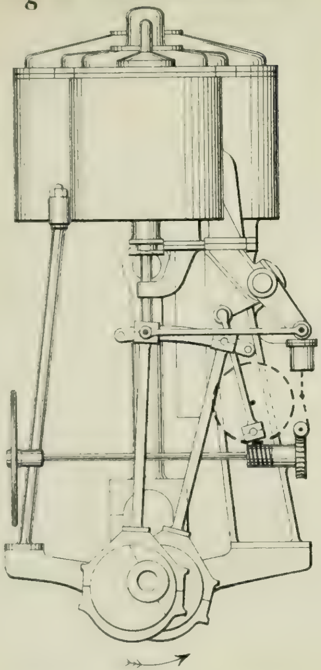


Fig. 17. *Side Elevation.*

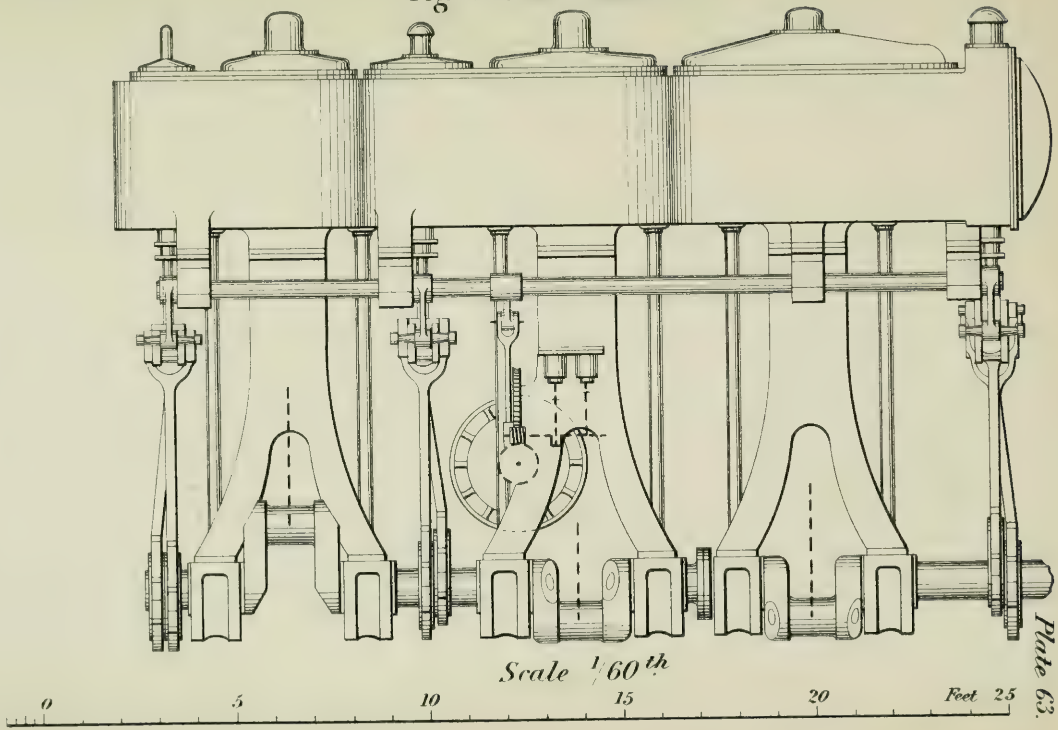


Plate 63.

FLUID-PRESSURE REVERSING GEAR.

Application to Marine Engines.

Fig. 18. *Side Elevation.*

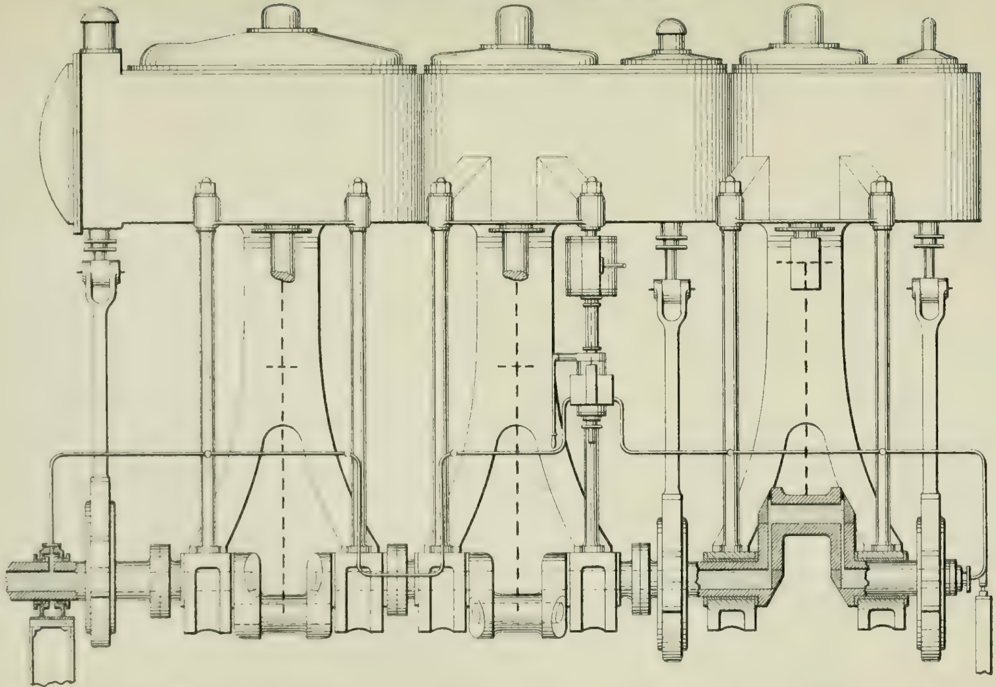
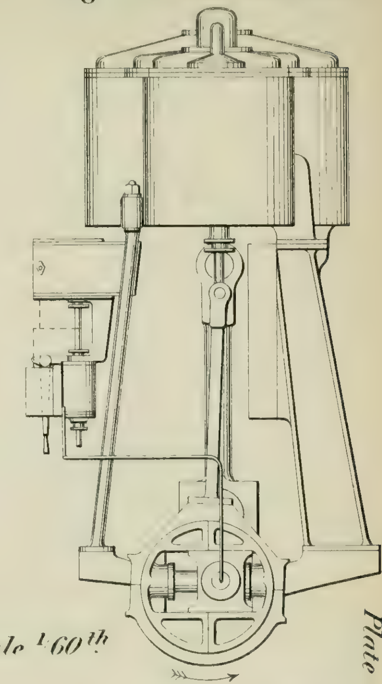


Fig. 19. *End Elevation.*



Scale 1/60th.

0 5 10 15 20 Feet 25

Plate 64.

Adjustable Eccentric for Marine Engines.

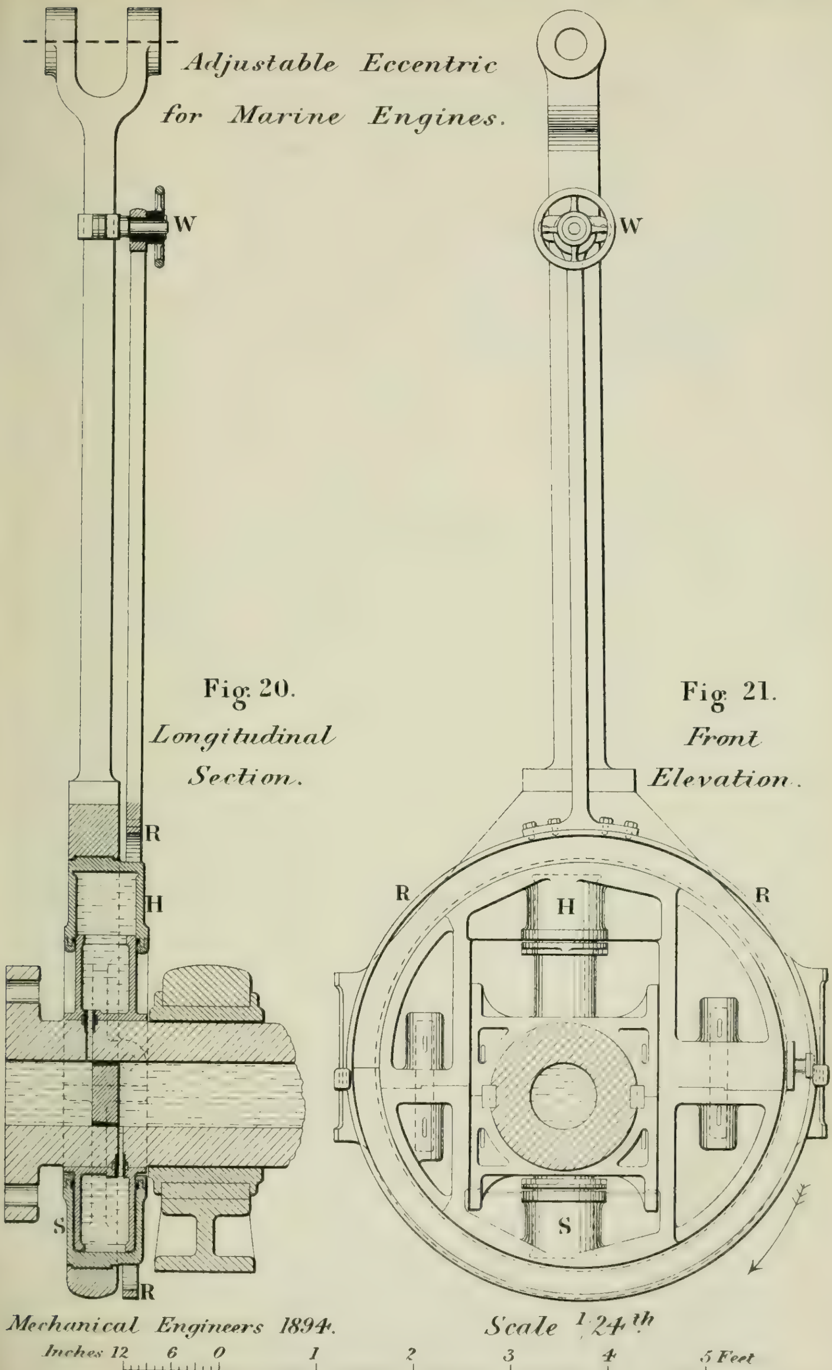


Fig. 20. *Longitudinal Section.*

Fig. 21. *Front Elevation.*

Mechanical Engineers 1894.

Scale 1/24th

Adjustable Eccentric for Marine Engines.

Fig: 22.

Sectional Plan.

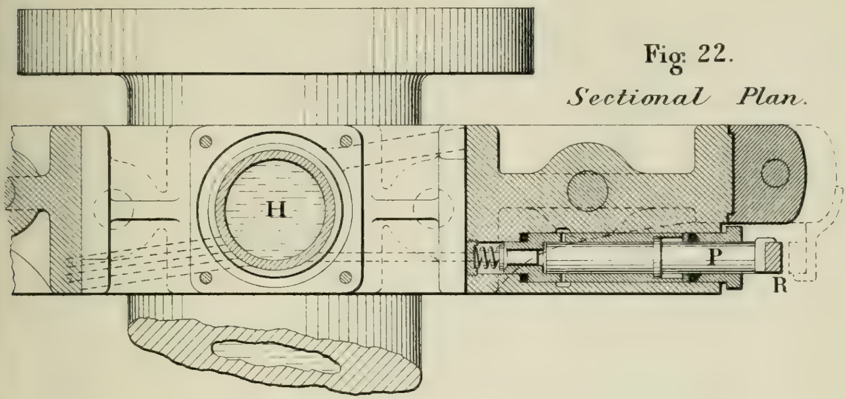
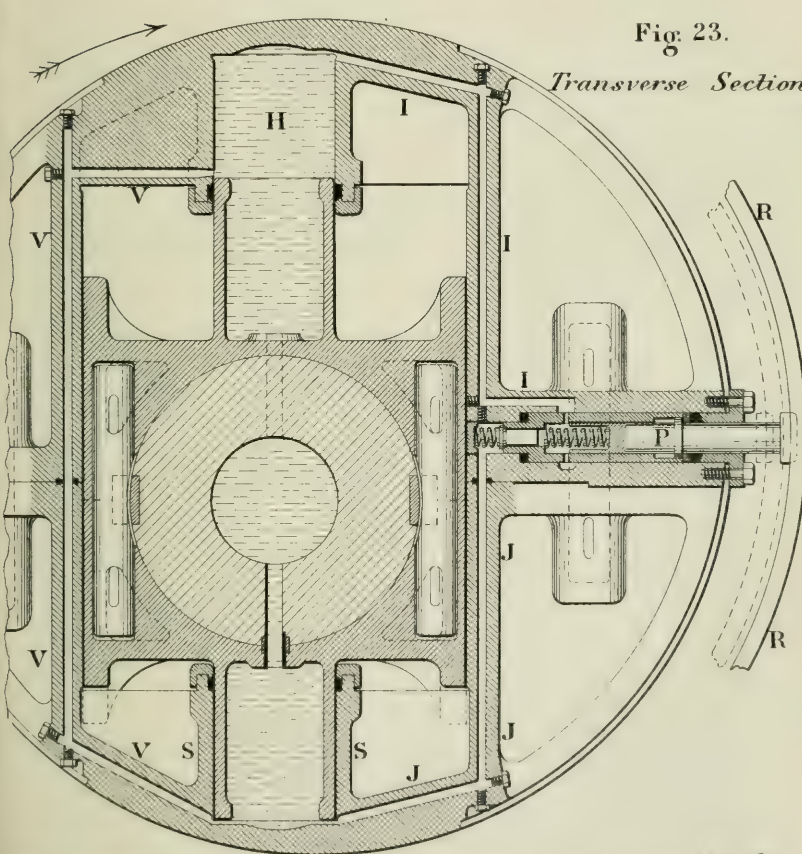


Fig: 23.

Transverse Section.



Mechanical Engineers 1894.

Scale 1/12th

Inches 12 6 0 1 2 Feet

Y

INSTITUTION

OF

MECHANICAL ENGINEERS.

ESTABLISHED 1847.

PROCEEDINGS.

1894.

PARTS 3–4.

PUBLISHED BY THE INSTITUTION,

19 VICTORIA STREET, WESTMINSTER, S.W.

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John Robinson, 1878–79.

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[Telegraphic address:—*Mech, London.* Telephone, 3264.]

Institution of Mechanical Engineers.

ESTABLISHED 1847.

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

[*Telegraph Address and Telephone No. appended within brackets.*]

1894.

HONORARY LIFE MEMBERS.

1890. H. R. H. Albert Edward, Prince of Wales, K.G., K.T., K.P., G.C.B., G.C.S.I., &c., Marlborough House, Pall Mall, London, S.W.

1892. Field Marshal H.R.H. the Duke of Cambridge, K.G., K.T., K.P., G.C.B., G.C.S.I., &c., Gloucester House, Park Lane, London, W.

1883. Abel, Sir Frederick Augustus, Bart., K.C.B., D.C.L., D.Sc., F.R.S., The Imperial Institute, Imperial Institute Road, London, S.W.; and 2 Whitehall Court, London, S.W. [*Imperial Institute, London.* 8743.]

1878. Crawford and Balcarres, The Right Hon. the Earl of, K.T., F.R.S., 2 Cavendish Square, London, W.; Haigh Hall, Wigan; and Observatory, Dunecht, Aberdeen.

1889. Eiffel, Gustave, 37 Rue Pasquier, Paris.

1888. Haughton, Rev. Samuel, M.D., D.C.L., LL.D., F.R.S., Trinity College, Dublin.

1883. Kennedy, Professor Alexander Blackie William, LL.D., F.R.S., 14 Old Queen Street, Westminster, S.W. [*Kinematic, London.*]

1878. Rayleigh, The Right Hon. Lord, F.R.S., 4 Carlton Gardens, London, S.W.; and Terling Place, Witham, Essex.

1888. Rosse, The Right Hon. the Earl of, K.P., D.C.L., LL.D., F.R.S., Birr Castle, Parsonstown, Ireland.

MEMBERS.

1890. Abbott, Arthur Harold, care of Messrs. Octavius Steel and Co., Calcutta, India: (or care of F. C. Abbott, 101 Lambeth Palace Road, London, S.E.)

1878. Abbott, Thomas, Newark Boiler Works, Newark [*Abbott, Newark.*]; and Arlington House, Retford.

1883. Abbott, William Sutherland, Locomotive Superintendent and Assistant Engineer, Alagoas Railway, Maceio, Brazil: (or care of George S. Abbott, Lime Villa, South Woodford, Essex.)

1861. Abel, Charles Denton, Messrs. Abel and Imray, 28 Southampton Buildings, London, W.C. [*Patentable, London.* 2729.]

1874. Abernethy, James, F.R.S.E., 4 Delahay Street, Westminster, S.W.

1894. Accles, William Sloane, Messrs. Grenfell and Accles, Holford Engineering Works, Perry Barr, Birmingham.

1892. Acland, Captain Francis Edward Dyke, Dock House, Billiter Street, London, E.C.

1876. Adams, Henry, 60 Queen Victoria Street, London, E.C. [*Viburnum, London.*]

1879. Adams, William, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.W.

1848. Adams, William Alexander (*Life Member*), Gaines, Worcester.

1881. Adams, William John, 35 Queen Victoria Street, London, E.C. [*Packing, London.* 1854.]

1871. Adamson, Joseph, Messrs. Joseph Adamson and Co., Hyde, near Manchester. [*Adamson, Hyde.*]

1851. Addison, John, Colehill Cottage, Fulham, London, S.W.

1889. Addy, George, Waverley Works, Sheffield. [*Milling, Sheffield.*]

1887. Ahmed Bey, Colonel, Imperial Naval Arsenal, Constantinople.

1891. Ahrbecker, Henry Conrad Vandepoel, Morts Dock and Engineering Co., Balmain, Sydney, New South Wales.

1893. Ainley, Henry, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1886. Aisbitt, Matthew Wheldon, 47 Mount Stuart Square, Cardiff. [*Aisbitt, Cardiff.*]

1886. Albright, John Francis, Messrs. R. E. Crompton and Co., 4 Mansion House Buildings, Queen Victoria Street, London, E.C.; and Savernake Lodge, Chelmsford.

1885. Alderson, George Beeton, Messrs. Allen Alderson and Co., Alexandria, Egypt; Norland House, Ramleh, Alexandria, Egypt: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1881. Alexander, Edward Disney, Engineer's Department, London County Council; and 12 Cardigan Road, Richmond, Surrey.

1875. Allan, George, New British Iron Works, Corngreaves, near Birmingham; and Corngreaves Hall, near Birmingham.

1885. Allcard, Harry, Messrs. Easterbrook Allcard and Co., Albert Works, Penistone Road, Sheffield.

1874. Allen, Francis, Messrs. Allen Alderson and Co., Gracechurch Street, Alexandria, Egypt: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1891. Allen, Marcus, Union Brass and Iron Works, Great Ancoats Street, and Phœnix Iron Works, Jersey Street, Manchester. [*Valves, Manchester. Nat.* 60.]

1881. Allen, Percy Ruskin, Woodberrie Hill, Loughton, Essex.

1884. Allen, Samuel Wesley, Exchange Buildings, Mount Stuart Square, Cardiff.

1885. Allen, William Henry, Messrs. W. H. Allen Son and Co., York Street Works, Lambeth, London, S.E. [*Pump, London.*]; and Queen's Engineering Works, Bedford. [*Pump, Bedford.*]

1882. Allen, William Milward, Principal Assistant Engineer, Engine Boiler and Employers' Liability Insurance Co., 12 King Street, Manchester.

1877. Alley, Stephen, Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow. [*Alley, Glasgow.* 673.]

1865. Alleyne, Sir John Gay Newton, Bart., Chevin, Belper.

1884. Alleyne, Reynold Henry Newton, 11 Avenue Victoria, Scarborough.

1872. Alliott, James Bingham, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham. [*Manloves, Nottingham.*]

1891. Allott, Charles Sneath, 46 Brown Street, Manchester. [*Allotted, Manchester. Nat.* 1952.]

1876. Allport, Charles James, 24 Woburn Place, Russell Square, London, W.C.; and Whitehall Club, Parliament Street, Westminster, S.W.

1871. Allport, Howard Aston, Dodworth Grove, Barnsley.

1884. Almond, Harry John, Cartagena and Herrerias Steam Tramways, 43 Muralla del Mar, Cartagena, Spain: (or care of Messrs. G. and W. Almond, 67 Willow Walk, London, S.E.)

1885. Amos, Ewart Charles, Mansion House Chambers, 11 Queen Victoria Street, London, E.C.; and Eastdene, St. James' Road, Sutton, Surrey. [*Drilling, London.*]

1867. Amos, James Chapman, Rose Cottage, Fairfax Road, Teddington, S.O., Middlesex.

1891. Anderson, Alexander Southerland, Chief Engineer, Ordnance Department, Ordnance Factory, Cawnpore, India.

1880. Anderson, Edward William, Messrs. Easton, Anderson and Goolden, Erith Iron Works, Erith, S.O., Kent; and Roydon Lodge, Erith, S.O., Kent.

1890. Anderson, Herbert William, Messrs. Hilton Anderson and Co., Manor Works, Halling, near Rochester.

1892. Anderson, John Wemyss, Walker Engineering Laboratories, University College, Liverpool.

1856. Anderson, William, D.C.L., F.R.S., Director-General of Ordnance Factories, Royal Arsenal, Woolwich; and Lesney House, Erith, S. O., Kent.

1891. Anderson, William, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.

1892. Andrew, Thomas, Rand Club, Johannesburg, Transvaal, South Africa.

1893. Angas, William Moore, Darlington Wagon and Engineering Works, Darlington.

1885. Anson, Frederick Henry, 15 Dean's Yard, Westminster, S.W.

1883. Appleby, Percy Vavasseur, Messrs. Appleby Brothers, 22 Walbrook, London, E.C.

1874. Aramburu y Silva, Fernando, Messrs. Aramburu and Sons, Cartridge Manufacturers, Calle de la Virgen de las Azucenas, Madrid: (or care of Manuel Cardenosa, 86 Great Tower Street, London, E.C.)

1891. Archbold, John, Eastwood Collieries, Eastwood, R.S.O., Notts.

1881. Archbold, Joseph Gibson, Manager, Blyth Dry Dock, Blyth, Northumberland.

1889. Archer, Charles Frederick, Messrs. Joseph Richmond and Co., 30 Kirby Street, Hatton Garden, London, E.C.

1874. Archer, David, 275 Pershore Road, Birmingham.

1883. Arens, Henrique, Messrs. Arens and Irmaos, Engineering Works, Rio de Janeiro, Brazil: (or care of Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.)

1882. Armer, James, Messrs. John Birch and Co., 11 Queen Street Place, London, E.C.; and The Moorings, 108 Wickham Road, Brockley, London, S.E.

1859. Armitage, William James, Farnley Iron Works, Leeds.

1894. Armour, James Glencairn, Surveyor, Bureau Veritas, Oriel Chambers, Water Street, Liverpool.

1858. Armstrong, The Right Hon. Lord, C.B., D.C.L., LL.D., F.R.S., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.

1866. Armstrong, George, Locomotive Department, Great Western Railway, Stafford Road Works, Wolverhampton.

1882. Armstrong, George Frederick, F.R.S.E., Professor of Engineering, The University, Edinburgh.

1876. Armstrong, William, Jun., Mining Engineer, Wingate Colliery, County Durham.

1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1873. Arnold, David Nelson, Clarendon Lodge, Burgoyne Road, Southsea, B.O., Portsmouth.

1894. Arnot, William, Glasgow Corporation Electric Lighting Station, 75 Waterloo Street, Glasgow. [*Induction, Glasgow.* 4665.]

1887. Arrol, Sir William, Dalmarnock Iron Works, Glasgow.

1887. Arteaga, Alberto de, Libertad 1357, Buenos Aires, Argentine Republic: (or care of M. Raggio-Carneiro, 129A Winchester House, Old Broad Street, London, E.C.)

1873. Ashbury, Thomas (*Life Member*), 5 Market Street, Manchester; and Ash Grove, Victoria Park, Longsight, Manchester. [*Thomas Ashbury, Manchester.*]

1888. Ashby, George, Tardeo, Bombay, India.

1890. Ashley, Thomas James, Messrs. Fawcett Preston and Co., Phœnix Foundry, Liverpool.

1884. Ashwell, Frank, Victoria Foundry, Sycamore Lane, Leicester. [*Iron, Leicester.* 100.]

1891. Ashworth, Henry, Ollerton, Bolton.

1890. Askham, John Unwin, Messrs. Askham Brothers and Wilson, Yorkshire Steel Works, Napier Street, Sheffield.

1890. Askham, Philip Unwin, Messrs. Askham Brothers and Wilson, Yorkshire Steel Works, Napier Street, Sheffield.

1881. Aspinall, John Audley Frederick, Chief Mechanical Engineer, Lancashire and Yorkshire Railway, Horwich, near Bolton; and Fern Bank, Heaton, Bolton.

1891. Asplen, Bernard, Southall: (or care of W. W. Asplen, Foxton Hall, Royston, Cambridgeshire.)

1877. Astbury, James, Smethwick Foundry, near Birmingham.

1890. Aston, John W., Chief Teacher of Mechanical Science, Municipal School of Art, Birmingham; and Messrs. G. E. Belliss and Co., Ledsam Street, Birmingham.

1886. Atkey, Albert Reuben, Robin Hood Cycle Co., Upper Parliament Street, Nottingham.

1889. Atkinson, Alexander, Jammu, Kashmir, India: (or care of Messrs. Grindlay and Co., 55 Parliament Street, Westminster, S.W.)

1875. Atkinson, Edward (*Life Member*), Messrs. Bramwell and Harris, 5 Great George Street, Westminster, S.W.; and 32 Park Road, West Dulwich, London, S.E.

1890. Atkinson, Edward Turner, London County Council, Spring Gardens, London, S.W.

1892. Atkinson, James, Amherst, Fallowfield, Manchester.

1892. Ault, Edwin, 47 Victoria Street, Westminster, S.W.

1892. Austin, James Meredith, 51 Waldeck Avenue, Bedford.

1882. Aveling, Thomas Lake, Messrs. Aveling and Porter, Rochester. [*Aveling, Rochester.*]

1891. Bagshaw, Walter, Victoria Foundry, Batley.

1886. Bailey, William, 14 Delahay Street, Westminster, S.W.

1885. Bailey, Sir William Henry, Albion Works, Salford, Manchester [*Beacon, Salford.*]; and Sale Hall, Cheshire.

1872. Bailly, Philimond, 282 Rue Royale, Bruxelles, Belgium.

1890. Bain, George, Locomotive Department, Egyptian Government Railways, Cairo, Egypt.

1880. Bain, William Neish, 40 St. Enoch Square, Glasgow; and Collingwood, 7 Aytoun Road, Pollokshields, Glasgow. [*Glacis, Glasgow.*]

1869. Bainbridge, Emerson, Nunnery Colliery Offices, New Haymarket, Sheffield.

1873. Baird, George, St. Petersburg; and Fulmer, Slough.

1890. Baker, Sir Benjamin, K.C.M.G., F.R.S. (*Life Member*), 2 Queen Square Place, Westminster, S.W.

1875. Bakewell, Herbert James, Engineer, Department of the Controller of the Navy, Admiralty, Whitehall, London, S.W.

1893. Baldwin, Alfred, M.P., Wilden Iron Works, Stourport.

1894. Baldwin, Arthur Hugh, Messrs. Kendall and Gent, Victoria Works, Springfield, Salford, Manchester. [*Tools, Manchester.* Nat. 330; Mutual 1330.]

1877. Bale, Manfred Powis, Appold Street, Finsbury, London, E.C.

1884. Balmokand, Rai Bahadur, Executive Engineer, 4th Division, Chenab Canal, Lahore, Punjaub, India.

1887. Bamlett, Adam Carlisle, Agricultural Engineering Works, Thirsk.

1892. Banister, George Henry, Carriage Department, Royal Arsenal, Woolwich.

1885. Barker, Tom Birkett, Scholefield Street, Birmingham. [*Gasengine, Birmingham.* 2530.]

1880. Barlow-Massicks, Thomas, Millom Iron Works, Millom, Cumberland.

1891. Barnes, John Edward Lloyd, Messrs. Sloan and Lloyd Barnes, Castle Chambers, 26 Castle Street, Liverpool. [*Technical, Liverpool.*]

1881. Barnett, John Davis, Assistant Mechanical Superintendent, Grand Trunk Railway, Stratford, Ontario, Canada.

1887. Barningham, James, 41 Victoria Buildings, Victoria Street, Manchester.

1884. Barr, Archibald, D.Sc., Professor of Engineering, The University, Glasgow.

1878. Barr, James, care of William McConnell, Underwood House, Paisley.

1882. Barrett, John James, 5 Chinchpoogly Road, Bombay, India.

1885. Barrie, William, Superintendent Engineer, Nippon Yusen Kaisha Steam Ship Co., 7B Bluff, Yokohama, Japan.

1887. Barringer, Herbert, 88 Bishopsgate Street Within, London, E.C.

1862. Barrow, Joseph, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]

1871. Barry, John Wolfe, C.B., 21 Delahay Street, Westminster, S.W. [*Wolfebarry, London.* 3024.]

1883. Bartlett, James Herbert, Middlesbrough, Kentucky, United States.

1887. Bate, Major Charles McGuire, R.E., War Office, Whitehall, London, S.W.

1885. Bateman, Henry, Superintending Engineer, Rangoon Tramways, Rangoon, India.

1891. Bates, Henry, Messrs. Hulse and Co., Ordsal Works, Regent Bridge, Salford, Manchester; and 30 Halliwell Terrace, Trafford Road, Salford, Manchester.

1891. Battle, Arthur Edwin, 359–361 Collins Street, Melbourne, Victoria: (or care of F. G. Battle, Whitehall, Potterhanworth, Lincoln.) [Reuter's Agency: *Battle, Melbourne.*]

1892. Baxter, Peter Macleod, Departamento de Talleres, Minas de Rio Tinto, Huelva, Spain.

1889. Bayford, William James, Engineer and Manager, Messrs. Meakin and Co., Brewers, Delhi, India.

1872. Bayliss, Thomas Richard, Belmont, Northfield, Birmingham.

1891. Baynes, John, Midland Railway-Carriage and Wagon Co., Suffolk House, Laurence Pountney Hill, London, E.C.

1877. Beale, William Phipson, Q.C., 10 New Court, Carey Street, London, W.C.; and 19 Upper Phillimore Gardens, Kensington, London, W.

1887. Beardmore, William, Parkhead Forge and Steel Works, Glasgow.

1893. Beare, Thomas Hudson, F.R.S.E., Professor of Engineering, University College, Gower Street, London, W.C.

1893. Beastow, William Henry, Messrs. Brooks and Doxey, Union Iron Works, West Gorton, Manchester; and Junction Iron Works, Miles Platting, Manchester; and 157 Hyde Road, West Gorton, Manchester.

1891. Beatty, Hazlitt Michael, Locomotive Superintendent, Western Railway, Cape Government Railways, Salt River, near Cape Town, Cape Colony; and Rosclare Camp Ground, Rondebosch, near Cape Town, Cape Colony.

1880. Beaumont, William Worby, 33 Norfolk Street, Strand, London, W.C.; and Melford, Palace Road, Tulse Hill, London, S.W.

1859. Beck, Edward (*Life Member*), Dallam Forge, Warrington; and Springfield, Warrington.

1873. Beck, William Henry, 115 Cannon Street, London, E.C.

1887. Beckwith, George, Enfield House, Fairlop Road, Leytonstone, London, N.E.

1891. Beckwith, George Charles, 17 Wind Street, Swansea. [*Beckwith, Swansea.*]

1875. Beckwith, John Henry, Managing Director, Messrs. Galloways, Knott Mill Iron Works, Manchester.

1882. Bedson, Joseph Phillips, Parkhurst, Middlesbrough.

1875. Beeley, Thomas, Engineer and Boiler Maker, Hyde Junction Iron Works, Hyde, near Manchester. [*Beeley, Hyde.*]

1888. Beldam, Asplan, 77 Gracechurch Street, London, E.C.

1885. Bell, Charles Lowthian, Clarence Iron Works, Middlesbrough; and Linthorpe, Middlesbrough. [*Bells, Middlesbrough.* 5510.]

1858. Bell, Sir Lowthian, Bart., F.R.S., Clarence Iron Works, Middlesbrough; Rounton Grange, Northallerton; and Reform Club, Pall Mall, London, S.W. [*Sir Lowthian Bell, Middlesbrough.*]

1879. Bellamy, Charles James, 195 Earl's Court Road, South Kensington, London, S.W.

1868. Belliss, George Edward, Steam Engine and Boiler Works, Ledsam Street, Birmingham [*Belliss, Birmingham.*]; and The Dell, King's Norton, near Birmingham.

1878. Belsham, Maurice, Messrs. Price and Belsham, 52 Queen Victoria Street, London, E.C.

1880. Benham, Percy, Messrs. Benham, 66 Wigmore Street, London, W. [*Benham, London.* 7065.]

1894. Bennett, James William, Messrs. Taylor and Lawson, Engineering Works, Batavia; and Alington, Dean Park, Bournemouth.

1894. Bentley, George, Messrs. Bentley and Jackson, Lodge Bank Works, Bury, Lancashire.

1890. Berkley, James Eustace, Locomotive and Carriage Superintendent, H.H. the Nizam's Guaranteed State Railways, Secunderabad, India.

1878. Berrier-Fontaine, Marc, Directeur des Constructions navales, Toulon, France.

1893. Berry, Henry, Croydon Works, Leeds.

1893. Berry, John Ferrier, care of Messrs. Howard Farrar and Co., P. O. Box 455, Johannesburg, Transvaal, South Africa.

1890. Bertram, Alexander, Wigan Coal and Iron Works, Wigan.

1891. Bertram, David Noble, Messrs. Bertrams, St. Katherine's Works, Sciennes, Edinburgh.

1861. Bessemer, Sir Henry, F.R.S., Denmark Hill, London, S.E.

1891. Best, Francis Edward, South Staffordshire Water Works, Shenstone, near Lichfield; and 1 Swan Walk, Chelsea Embankment, London, S.W.

1893. Betts, Samuel, Locomotive Superintendent, Oxelösund-Fleu-Westmanlands Railway, Eskilstuna, Sweden.

1891. Bevis, Alfred William, The Nest, Harborne, Birmingham.

1866. Bevis, Restel Ratsey, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead; and Manor Hill, Birkenhead.

1892. Bickle, Thomas Edwin, Messrs. Bickle and Co., Great Western Docks, Plymouth. [*Engineers, Plymouth.* 176.]

1885. Bicknell, Arthur Channing, 42 Pelham Street, South Kensington, London, S.W.

1883. Bicknell, Edward, care of Bank of Bengal, Calcutta, India: (or 8 Canynge Square, Clifton, Bristol.)

1884. Bika, Léon Joseph, Locomotive Engineer-in-Chief, Belgian State Railway, 29 Rue des Palais, Bruxelles, Belgium.

1888. Billinton, Robert John, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton.

1890. Bingham, Charles Henry, Messrs. Walker and Hall, Electro Works, Howard Street, Sheffield. [*Bingham, Sheffield.*]

1887. Binnie, Alexander Richardson, Engineer, London County Council, Spring Gardens, London, S.W.; and 77 Ladbroke Grove, Notting Hill, London, W.

1877. Birch, Robert William Peregrine, 5 Queen Anne's Gate, Westminster, S.W.

1891. Bird, George, Messrs. James Bartle and Co., Western Iron Works, Notting Hill, London, W.

1880. Birkett, Herbert, Messrs. L. Sterne and Co., 28 Victoria Street, Westminster, S.W.; and 32 Ebury Street, Pimlico, London, S.W.

1879. Black, William, Messrs. Black Hawthorn and Co., Gateshead. [*Blackthorn, Newcastletyne.*]

1891. Black, William, 72 Bute Road, Cardiff.

1891. Blackburn, Arthur Henry, Fuel Economizer Co., Matteawan, New York, United States.

1891. Blackburn, George William, Messrs. T. Green and Son, Smithfield Iron Works, Leeds.

1890. Blackburn, John, Resident Engineer, Colne Valley Water Works, Bushey, Watford.

1862. Blake, Henry Wollaston, F.R.S., Messrs. James Watt and Co., 90 Leadenhall Street, London, E.C.

1886. Blandford, Thomas, Corbridge, R.S.O., Northumberland.

1881. Blechynden, Alfred, Naval Construction and Armaments Works, Barrow-in-Furness.

1892. Blechynden, John, Shanghai Engine Works, Birt's Wharf, Shanghai, China. [*Steam, Shanghai.* 176.]

1867. Bleckly, John James, Bewsey Iron Works, Warrington; and Daresbury Lodge, Altrincham.

1882. Blundstone, Samuel Richardson, Catherine Chambers, 8 Catherine Street, Strand, London, W.C.

1884. Bocquet, Harry Claude, Locomotive Carriage and Wagon Superintendent, North West Argentine Railway, Tucuman, Argentine Republic: (or care of Mrs. Bocquet, Llanwye, Hampton Park, Hereford.)

1863. Boeddinghaus, Julius, Electrotechniker, Düsseldorf, Germany.

1884. Bone, William Lockhart, Works of the Ant and Bee, West Gorton, Manchester.

1892. Booth, John William, Union Foundry, Rodley, near Leeds.

1890. Booth, Robert, 110 Cannon Street, London, E.C.

1883. Booth, William Stanway, Messrs. John Jameson and Son, Bow Street Distillery, Dublin.

1880. Borodin, Alexander, Engineer-Director, Russian South Western Railways, Kieff, Russia.

1888. Borrows, William, Messrs. Edward Borrows and Sons, Providence Foundry, Sutton, St. Helen's, Lancashire.

1891. Boswell, Samuel, Messrs. Galloways, Knott Mill Iron Works, Manchester.

1888. Boulding, Sidney, Messrs. Green and Boulding, 21 Featherstone Street, London, E.C. [*Temperature, London.*]

1886. Boult, Alfred Julius, Messrs. Boult and Wade, 323 High Holborn, London, W.C. [*Boult, London.* 2896.]

1878. Bourdon, François Edouard, 74 Faubourg du Temple, Paris: (or care of Messrs. Negretti and Zambra, Holborn Viaduct, London, E.C.)

1886. Bourne, Thomas Johnstone, Imperial Chinese Railways, Tientsin, China: (or care of Mrs. Bourne, 16 Park Road, Southborough, Tunbridge Wells.)

1879. Bourne, William Temple, Messrs. Bourne and Grove, Bridge Steam Saw Mills, Worcester.

1891. Bousfield, John Ebenezer, 4 South Street, Finsbury, London, E.C. [*Invention, London.* 169.]

1879. Bovey, Henry Taylor, LL.D., Professor of Engineering, McGill University, Montreal, Canada.

1880. Bow, William, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]

1888. Bowen, Edward (*Life Member*), Locomotive and Carriage Superintendent, Porto Alegre and New Hamburg Railway, Rio Grande do Sol, Brazil: (or care of Benjamin Packham, 18 Upper Wellington Road, Brighton.)

1858. Bower, John Wilkes (*Life Member*), Meredale, Rugby Road, Leamington Spa.

1892. Bowker, Arthur F., Engineer, Mid-Kent Water Works, Snodland, S.O., Kent.

1893. Boyd, James Tennant, Boyd's Ice Factory, Bombay, India.

1890. Boyd, John White, 6 Oswald Street, Glasgow. [*Silent, Glasgow.*]

1884. Boyer, Robert Skeffington, 46 Mount Stuart Square, Cardiff.

1882. Bradley, Frederic, Sandhills, Liverpool; Clensmore Foundry, Kidderminster; and Wolverley House, Southport.

1878. Braithwaite, Charles C., 35 King William Street, London Bridge, London, E.C.

1875. Braithwaite, Richard Charles, Messrs. Braithwaite and Kirk, Crown Bridge Works, Westbromwich. [*Braithwaite, Westbromwich.*]

1854. Bramwell, Sir Frederick Joseph, Bart., D.C.L., LL.D., F.R.S., Messrs. Bramwell and Harris, 5 Great George Street, Westminster, S.W. [*Wellbram, London.* 3060.]

1892. Brand, David Jollie, Messrs. Brand and Dryburgh, Cleveland Foundry and Engine Works, Townsville, North Queensland.

1888. Bratt, Augustus Hicks Henery, Le Kueh Coal and Iron Mines, Kiangsu, North China; Astor House, Shanghai, China: (or care of Messrs. David Owen and Co., 50 Exchange Chambers, Bixteth Street, Liverpool.) [*Bratt, Shanghai.*]

1885. Brearley, Benjamin J., Union Plate Glass Works, St. Helen's.

1889. Brebner, Samuel Gordon, Chief Mechanical Engineer, Small Arms Ammunition Factory, Kirkee, Poona, India; and 2 Swallowfield Road, Charlton, Kent.

1891. Brewster, Edwin Henry George, 12 Delahay Street, Westminster, S.W.

1890. Brewster, Walter Seckford, Messrs. Beyer Peacock and Co.; High Street, Carlton, Hurstville, near Sydney, New South Wales.

1891. Bridie, Ronald Hope, St. Benet's Place, Gracechurch Street, London, E.C. [*Enwheeling, London.*]

1887. Brier, Henry, Scotch and Irish Oxygen Co., Rosehill Works, Polmadie, Glasgow.

1889. Briggs, Charles, care of Robert Briggs, Howden.

1881. Briggs, John Henry, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.; and Howden.

1886. Bright, William, Manager, Fairwood Tin-Plate Works, Gowerton, R.S.O., Glamorganshire.

1894. Brindley, George Samuel, Cliffe House, Smethwick, near Birmingham.

1891. Broadbent, William, Messrs. Thomas Broadbent and Sons, Central Iron Works, Huddersfield. [*Broadbent, Huddersfield.* 102.]

1891. Brock, Cameron William Harrison, 18 Lullington Road, Anerley, London, S.E.

1865. Brock, Walter, Messrs. Denny and Co., Engine Works, Dumbarton. [*Lennox, Dumbarton.* 1 and 15.]

1890. Brodie, John Alexander, 3 Cook Street, Liverpool.

1852. Brogden, Henry (*Life Member*), Hale Lodge, Altrincham, near Manchester.

1890. Brogden, Thomas, Messrs. Appleby and Brogden, Sandside, Scarborough.

1892. Bromiley, William J., Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton.

1892. Brooke, John Walter, Adrian Iron Works, Lowestoft.

1892. Brooke, Robert Grundy, Messrs. Holden and Brooke, St. Simon's Works, Salford, Manchester. [*Influx, Manchester.*]

1884. Brook-Fox, Frederick George, care of Messrs. Grindlay and Co., 55 Parliament Street, Westminster, S.W.: (or care of Messrs. H. S. King and Co., 65 Cornhill, London, E.C.)

1880. Brophy, Michael Mary, Messrs. James Slater and Co., 251 High Holborn, London, W.C.

1874. Brotherhood, Peter, 15 and 17 Belvedere Road, Lambeth, London, S.E.; and 15 Hyde Park Gardens, London, W. [*Brotherhood, London.*]

1886. Brown, Andrew, Willis Road, Erith, S.O., Kent: (or care of P. B. Brown, 660 Grimesthorpe Road, Sheffield.)

1866. Brown, Andrew Betts, F.R.S.E., Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.

1891. Brown, Arthur Mogg, P.O. Box 491, Johannesburg, Transvaal, South Africa.

1885. Brown, Benjamin, Widnes Foundry, Widnes.

1880. Brown, Francis Robert Fountaine, Mechanical Superintendent, Intercolonial Railway of Canada, Moncton, New Brunswick, Canada.

1889. Brown, Frederick Alexander William, Lieutenant R.A., Inspector of Ordnance Machinery, The Castle, Cape Town, Cape Colony: (or 42 Fermoy Road, St. Peter's Park, London, W.)

1881. Brown, George William, Messrs. Huntley Boorne and Stevens, Reading Tin Works, Reading.

1892. Brown, James Fiddes, 147 Woodbridge Road, Ipswich.

1884. Brown, Oswald, 28 Victoria Street, Westminster, S.W. [*Acqua, London.*]

1890. Brown, Robert, Manor House Engine Works, Far Cotton, Northampton.

1888. Brown, William, Messrs. W. Simons and Co., London Works, Renfrew.

1892. Brown, William, Messrs. Siemens Brothers and Co., Woolwich.

1887. Browne, Frederick John, Messrs. Austin Wood Browne and Co., Austin Foundry, Parkfield Street, Islington, London, N.

1874. Browne, Tomyns Reginald, Deputy Locomotive Superintendent, East Indian Railway, Jamalpur, Bengal, India: (or care of Messrs. W. Watson and Co., 27 Leadenhall Street, London, E.C.)

1874. Bruce, Sir George Barclay, 3 Victoria Street, Westminster, S.W.

1889. Bruce, Robert, 30 Great St. Helen's, London, E.C. [*Tangential, London.*]

1867. Bruce, William Duff, Vice-Chairman, Port Commission, Calcutta; and 23 Roland Gardens, South Kensington, London, S.W.

1888. Bruff, Charles Clarke, Coalport China Co., Coalport, near Ironbridge, Salop.

1873. Brunel, Henry Marc, 21 Delahay Street, Westminster, S.W. [3024.]

1892. Brunlees, John, 12 Victoria Street, Westminster, S.W. [3245.]

1891. Brunner, Adolphus, 55 AIII Königin Strasse, Munich, Bavaria: (or care of L. F. Brunner, 257 Romford Road, Forest Gate, London, E.)

1887. Brunton, Philip George, Resident Engineer, Department of Roads and Bridges, Public Works Office, Sydney, New South Wales: (or care of J. D. Brunton, 19 Great George Street, Westminster, S.W.)

1884. Bryan, William B., Engineer, East London Water Works, Lea Bridge, Clapton, London, N.E.

1892. Buckley, John T., Messrs. Stevenson and Co., Canal Foundry, Preston; and 50 Poulton Street, Kirkham, near Preston.

1873. Buckley, Robert Burton, Arrah, Shahabad, Bengal, India: (or care of H. Burton Buckley, 1 St. Mary's Terrace, Paddington, London, W.)

1877. Buckley, Samuel, Messrs. Buckley and Taylor, Castle Iron Works, Oldham.

1886. Buckney, Thomas, Messrs. E. Dent and Co., 61 Strand, London, W.C.

1887. Buckton, Walter, 27 Ladbroke Square, London, W.

1878. Buddicom, Harry William, Penbedw, Nannerch, near Mold.

1886. Budenberg, Christian Frederick, Messrs. Schäffer and Budenberg, 1 Southgate, St. Mary's Street, Manchester; and Bowden Lane, Marple, Stockport. [*Manometer, Manchester.* 899.]

1882. Budge, Enrique, Engineer-in-Chief, Harbour Works, Valparaiso, Chile: (or care of Messrs. Rose-Innes Cox and Co., 4 Fenchurch Avenue, London, E.C.)

1881. Bulkley, Henry Wheeler, N.Y. Times Building, 41 Park Row, New York, United States.

1884. Bullock, Joseph Howell, General Manager, Pelsall Coal and Iron Works, near Walsall; and Glenhurst, Lichfield Road, Walsall.

1882. Bulmer, John, Spring Garden Engineering Works, Pitt Street, Newcastle-on-Tyne.

1891. Bumsted, Francis Dixon, Cannock Chase Foundry and Engine Works, Hednesford, near Stafford.

1884. Bunning, Charles Ziethen, The Borax Co., 9 Mehmet Ali Pacha Khan, Constantinople.

1884. Bunt, Thomas, Superintendent Engineer, Kiangnan Arsenal, Shanghai, China: (or care of R. Pearce, Lanarth House, Holders Hill, Hendon, London, N.W.)

1884. Bunting, George Albert, Locomotive Superintendent, Estrada de Ferro Recife e São Francisco, Pernambuco, Brazil.

1885. Burder, Walter Chapman, Messrs. Messenger and Co., Loughborough.

1891. Burgess, Francis Chassereau Boughey, Office of Director General of Railways, Technical Section, Simla, India.

1894. Burke, Michael James, Locomotive and Carriage Superintendent, Morvi Railway, Morvi, India.

1881. Burn, Robert Scott, Oak Lea, Edgeley Road, near Stockport.

1893. Burnes, Thomas, Fleet Engineer, R.N., H.M.S. "Hotspur," Chatham.

1879. Burnet, Lindsay, Moore Park Boiler Works, Govan, near Glasgow. [*Burnet, Glasgow.* 1513.]

1878. Burnett, Robert Harvey, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1878. Burrell, Charles, Jun., Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford. [*Burrell, Thetford.*]

1885. Burrell, Frederick John, Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford. [*Burrell, Thetford.*]

1887. Burstal, Edward Kynaston, Messrs. Stevenson and Burstal, 38 Parliament Street, Westminster, S.W.

1890. Burstall, Henry Robert John, 14 Old Queen Street, Westminster, S.W.; and 76 King's Road, London, N.W.

1884. Butcher, Joseph John, Heine Safety Boiler Co., Electrical Exchange Building, 136 Liberty Street, New York, United States.

1882. Butler, Edmund, Kirkstall Forge, near Leeds. [*Forge, Kirkstall.*]

1892. Butler, Henry William, 1 Bakehouse Court, Godliman Street, London, E.C.

1884. Butler, Hugh Myddleton, Kirkstall Forge, near Leeds.

1891. Butler, James, Victoria Iron Works, Halifax; and Longfield, Halifax.

1888. Butter, Frederick Henry, Carriage Department, Royal Arsenal, Woolwich; and 4 Hanover Road, Brookhill Park, Plumstead.

1891. Butter, Henry Joseph, Messrs. Tannett Walker and Co., Leeds; and Claremont, Burrage Road, Plumstead.

1894. Butterworth, Joseph, Messrs. Lancaster and Tonge, Pendleton, Manchester.

1892. Byrne, Francis Furlong, Engineer, Harbour Office, Drogheda, Ireland. [*Byrne, Engineer, Drogheda.*]

1887. Caiger, Emery John, Messrs. E. J. Caiger and Co., 77 Billiter Buildings, Billiter Street, London, E.C. [*Caiger, London.*]

1886. Cairnes, Frederick Evelyn, Bridgewater Hotel, Worsley, near Manchester.

1889. Callan, William, River Plate Fresh Meat Co., 2 Coleman Street, London, E.C.

1886. Cambridge, Henry, Stuart Chambers, Mount Stuart Square, Cardiff.

1893. Campbell, Andrew Chisholm, Messrs. James Campbell and Sons, Vulcan Engine Works, William Moult Street, Liverpool.

1877. Campbell, Angus, Logie, Mussoorie, N. W. Provinces, India.

1880. Campbell, Daniel, Messrs. Campbell, Macmaster and Co., Botolph House, 10 Eastcheap, London, E.C. [*Duke, London.* 2011.]

1869. Campbell, James, Hunslet Engine Works, Leeds. [*Engineco, Leeds.*]

1893. Campbell, James Alexander Miller, Messrs. James Campbell and Sons, Vulcan Engine Works, William Moult Street, Liverpool.

1882. Campbell, John, Messrs. R. W. Deacon and Co., Kalimaas Works, Soerabaya, Java.

1892. Campbell, William Walker, Messrs. Campbell and Calderwood, Soho Engine Works, Paisley. [*Soho, Paisley.* 162.]

1885. Capito, Charles Alfred Adolph, 2 Penywern Road, Earl's Court, London, S.W.

1892. Capper, David Sing, Professor of Mechanical Engineering, King's College, Strand, London, W.C.

1860. Carbutt, Sir Edward Hamer, Bart., 19 Hyde Park Gardens, London, W.; and Nanhurst, Cranleigh, Guildford.

1878. Cardew, Cornelius Edward, Locomotive and Carriage Superintendent, Burma State Railways, Insein, Burma; care of Messrs. King King and Co., Bombay, India: (or care of Rev. J. H. Cardew, Wingfield Rectory, Trowbridge.)

1875. Cardozo, Francisco Corrêa de Mesquita (*Life Member*), Messrs. Cardozo and Irmâo, Pernambuco Engine Works, Pernambuco, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1878. Carlton, Thomas William, Marlow House, New Swindon, Wiltshire.

1892. Carnegie, David, Royal Laboratory, Royal Arsenal, Woolwich.

1869. Carpmael, Frederick, 106 Croxted Road, West Dulwich, London, S.E.

1866. Carpmael, William, 24 Southampton Buildings, London, W.C. [*Carpmael, London.* 2608.]

1877. Carr, Robert, 1 West Pier, London Docks, London, E.

1892. Carrack, Charles, Messrs. Crossley Brothers, 5 Hounds Gate, Nottingham.

1884. Carrick, Henry, Messrs. Carrick and Wardale, Redheugh Engine Works, Gateshead; and Newbrough Lodge, Fourstones, R.S.O., Northumberland. [*Wardale, Gateshead.*]

1885. Carter, Herbert Fuller, Calle de Gante 8, Ciudad de Mexico, Mexico: (or care of H. Maynard Carter, 126 Wool Exchange, Basinghall Street, London, E.C.)

1877. Carter, William, Manager, The Hydraulic Engineering Company, Chester.

1891. Carter, William Charles, Mansion House Chambers, Queen Victoria Street, London, E.C. [*Tympanum, London.*]

1888. Castle, Frank, Royal College of Science, Exhibition Road, South Kensington, London, S.W.

1891. Caswell, Samuel John, 31 Sakai Machi, Kobe, Japan.

1892. Causer, William George, Brighton Villa, Handsworth, R.O., Birmingham.

1883. Cawley, George, 29 Great George Street, Westminster, S.W.

1892. Chadwick, Osbert, C. M. G., Crown Agents' Department, Colonial Office, Downing Street, London, S.W.; and 11 Airlie Gardens, Kensington, London, W.

1894. Chaffey, George, Messrs. Chaffey Brothers, 35 Queen Victoria Street, London, E.C.

1876. Challen, Stephen William, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham. [*Derwent, Birmingham.*]

1892. Chalmers, George, St. John del Rey Mining Co., 28 Tower Chambers, Finsbury Pavement, London, E.C.

1886. Chalmers, John Reid, 18 Hemingford Road, Barnsbury, London, N.

1884. Chamberlain, John, Engineer's Department, Gas Light and Coke Co., Horseferry Road, Westminster, S.W.

1890. Chandler, Noel, Cannock Chase Foundry and Engine Works, Hednesford. near Stafford.

1887. Chapman, Alfred Crawhall, 3 St. Nicholas' Buildings, Newcastle-on-Tyne.

1888. Chapman, Arthur, Assam Railways and Trading Co., 1 Clive Ghat Street, Calcutta, India; The New Club, Calcutta, India: (or St. Andrew's Cottage, Bury St. Edmund's.)

1882. Chapman, Hedley, Messrs. Chapman Carverhill and Co., Scotswood Road, Newcastle-on-Tyne.

1866. Chapman, Henry, 69 Victoria Street, Westminster, S.W. [*Tubalcain, London.*]; and 10 Rue Laffitte, Paris.

1878. Chapman, James Gregson, Messrs. Fawcett Preston and Co., Phœnix Foundry, Liverpool; and 25 Austinfriars, London, E.C. [*Fawcett, London.*]

1887. Chapman, Joseph Crawhall, 70 Chancery Lane, London, W.C.; and St. Mildred's, Lovelace Gardens, Surbiton.

1893. Charlesworth, Sheard, Messrs. S. Charlesworth and Co., Richmond Hill Iron Works, Oldham. [*Charlesworth, Engineers, Oldham.* 63.]

1885. Charnock, George Frederick, Engineering Department, Technical College, Bradford.

1877. Chater, John, Messrs. Henry Pooley and Son, 89 Fleet Street, London, E.C.

1890. Chater, John Richard, Madras Railway, Madras, India; and care of John Chater, 223 Peckham Rye, London, S.E.

1891. Chatterton, Alfred, Professor of Engineering, College of Engineering, Madras, India.

1887. Chatwin, James, Victoria Works, Great Tindal Street, Ladywood, Birmingham.

1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton; and High Lawn, Broad Oak Park, Worsley, near Manchester.

1873. Cheesman, William Talbot, Hartlepool Rope Works, Hartlepool.

1881. Chilcott, William Winsland, The Terrace, H.M. Dockyard, Sheerness.

1880. Churchward, George Dundas, Locomotive Superintendent, Imperial Chinese Railways, care of H.B.M.'s Consulate, Tientsin, North China: (or care of A. W. Churchward, London Chatham and Dover Railway, Queenborough Pier, Queenborough.)

1894. Churchward, George Jackson, Great Western Railway Carriage Works, Swindon.

1891. Clark, Augustus, Bowman's Heirs, Pernambuco, Brazil.

1871. Clark, Christopher Fisher, Mining Engineer, Garswood Coal and Iron Co., Park Lane Collieries, Wigan; and Cranbury Lodge, Park Lane, Wigan. [*Park Lane, Wigan.*]

1878. Clark, Daniel Kinnear, 8 Buckingham Street, Adelphi, London, W.C.

1867. Clark, George, Southwick Engine Works, near Sunderland.

1889. Clark, Thomas Alexander, Superintendent of Workshops, George Heriot's Hospital School, Edinburgh.

1885. Clarke, Leslie, 132 Westbourne Terrace, Hyde Park, London, W.

1894. Clarkson, Charles, 100 Oakfield Road, Cannon Hill, Birmingham.

1891. Clarkson, Thomas, Grove Villa, Carshalton Grove, Sutton, Surrey.

1892. Clay, Charles Butler, National Telephone Co., Oxford Court, Cannon Street, London, E.C.

1886. Clayton, Samuel, St. Thomas' Engine Works, Sunbridge Road, Bradford.

1882. Clayton, William Wikeley, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds. [*Loco, Leeds.* 504.]

1890. Cleathero, Edward Thomas, Messrs. Cleathero and Nichols, Phœnix Works, Boleyn Road, Kingsland, London, N.; and 16 Tollington Place, London, N.

1890. Cleaver, Arthur, Engineer, Nottingham Laundry Co., Sherwood, near Nottingham; and Hornby House, Sherwood, near Nottingham.

1890. Cleland, William, Sheffield Testing Works, Blonk Street, Sheffield.

1871. Cleminson, James, Dashwood House, 9 New Broad Street, London, E.C. [*Catamarca, London.*]

1873. Clench, Frederick, Newland House, Lincoln.

1885. Clifton, George Bellamy, Great Western Railway Electric Light Works, 150 Westbourne Terrace, Paddington, London, W.

1885. Close, John, Jun., York Engineering Works, Leeman Road, York.

1885. Clutterbuck, Herbert, Engineers' Department, London County Council, Spring Gardens, London, S.W.

1882. Coates, Joseph, 117 Cannon Street, London, E.C.

1881. Cochrane, Brodie, Mining Engineer, Aldin Grange, Durham.

1858. Cochrane, Charles, Woodside Iron Works, near Dudley; and Green Royde, Pedmore, near Stourbridge.

1887. Cochrane, George, Resident Engineer, London Hydraulic Power Works, 46 Holland Street, Blackfriars Road, London, S.E.

1885. Cochrane, John, Grahamston Foundry and Engine Works, Barrhead, near Glasgow. [*Cochrane, Barrhead.*]

1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.

1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne; and Oakfield House, Gosforth, Newcastle-on-Tyne.

1864. Coddington, William, M.P., Ordnance Cotton Mill, Blackburn; and Wycollar, Blackburn.

1889. Coey, Robert, Assistant Locomotive Engineer, Great Southern and Western Railway, Inchicore Works, near Dublin.

1889. Colam, William Newby, Billiter Buildings, Billiter Street, London, E.C. [*Colam, London.*]

1892. Cole, Henry Aylwin Bevan, 79½ Gracechurch Street, London, E.C. [*Carbuncle, London.*]

1878. Coles, Henry James, Sumner Street, Southwark, London, S.E.

1877. Coley, Henry, Mansion House Chambers, Queen Victoria Street, London, E.C.

1892. Collen, Robert Henry, 10 Dover Road, Northfleet, S.O., Kent.

1884. Collenette, Ralph, Fairfield House, Idle, near Bradford.

1884. Coltman, John Charles, Messrs. Huram Coltman and Son, Engineering Works, Meadow Lane, Loughborough.

1878. Colyer, Frederick, 18 Great George Street, Westminster, S.W.

1888. Combe, Abram, Messrs. Combe Barbour and Combe, Falls Foundry, Belfast.

1889. Common, John Freeland Fergus, 4 Bute Crescent, Cardiff.

1881. Compton-Bracebridge, John Edward, Messrs. Easton Anderson and Goolden, 3 Whitehall Place, London, S.W.

1888. Constantine, Ezekiel Grayson, 32 Victoria Street, Manchester. [*Constant, Manchester.*]

1886. Conyers, Sidney Ward, Railway Construction Branch, Public Works Department, Sydney, New South Wales.

1874. Conyers, William, National Mortgage and Agency Co. of New Zealand, Melbourne, Victoria.

1888. Cook, John Joseph, Messrs. Robinson Cooks and Co., Atlas Foundry, St. Helen's, Lancashire.

1892. Cooke, Rupert Thomas, 51 Angus Street, Roath, Cardiff.

1877. Cooper, Arthur, North Eastern Steel Co., Royal Exchange, Middlesbrough.

1883. Cooper, Charles Friend, Messrs. Paterson and Cooper, Telegraph Works, Pownall Road, Dalston, London, N.E. [*Patella, London.* 1140.]

1877. Cooper, George, Pencliffe, Alleyne Road, West Dulwich, London, S.E.

1891. Cooper, Myles, 36 Victoria Street, Manchester.

1874. Cooper, William, Neptune Engine Works, Hull. [*Neptune, Hull.*]

1881. Coote, Arthur, Messrs. R. and W. Hawthorn Leslie and Co., Hebburn, Newcastle-on-Tyne.

1881. Copeland, Charles John, 11 Redcross Street, Liverpool.

1885. Coppée, Evence, 223 Avenue Louise, Bruxelles, Belgium.

1892. Corin, Philip Burne, Messrs. J. M. B. Corin and Son, Anchor Foundry, Penzance.

1848. Corry, Edward, 9 New Broad Street, London, E.C.

1881. Cosser, Thomas, McLeod Road Iron Works, Kurrachee, India : (or care of Messrs. Ironside Gyles and Co., 1 Gresham Buildings, Guildhall, London, E.C.)

1883. Cotton, Henry Streatfeild, London Hydraulic Power Co., Palace Chambers, Bridge Street, Westminster, S.W.

1894. Cottrill, John Ormerod, Bee Hive Works, Bolton.

1887. Coulman, John, Hull and Barnsley Railway, Spring Head Works, Hull.

1868. Coulson, William, Carlton Grove, Carlton Miniott, Thirsk.

1878. Courtney, Frank Stuart, Messrs. Easton Anderson and Goolden, 3 Whitehall Place, London, S.W.; and 76 Redcliffe Square, South Kensington, London, S.W.

1875. Coward, Edward, Messrs. Melland and Coward, Cotton Mills and Bleach Works, Heaton Mersey, near Manchester.

1875. Cowen, Edward Samuel, Messrs. G. R. Cowen and Co., Beck Works, Brook Street, Nottingham; and 9 The Ropewalk, Nottingham. [*Cowen, Nottingham.* 87.]

1880. Cowper, Charles Edward, 6 Great George Street, Westminster, S.W.

1892. Cowper-Coles, Sherard Osborn, 11 Hatton Garden, London, E.C.; and 16 Adam Street, Manchester Square, London, W.

1878. Coxhead, Frederick Carley, 27 Leadenhall Street, London, E.C.

1887. Crabbe, Alexander, 4 Hawkhill Place, Dundee.

1866. Craven, William, Messrs. Craven Brothers, Vauxhall Iron Works, Osborne Street, Manchester. [*Vauxhall, Manchester.* 659.]

1894. Craven, William H. S., Messrs. Craven Brothers, Vauxhall Iron Works, Osborne Street, Manchester. [*Vauxhall, Manchester.* 659.]

1889. Cribb, Frederick James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.

1884. Crighton, John, Messrs. Crighton and Co., 20 Exchange Buildings, St. Mary's Gate, Manchester. [*Vacuum, Manchester.*]

1893. Crippin, Thomas Henry, Messrs. John Hetherington and Sons, Manchester; and 66 Chorlton Road, Manchester.

1883. Croft, Henry, M.P., Chemanns, Vancouver Island.

1878. Crohn, Frederick William, 14 Burney Street, Greenwich, London, S.E.

1877. Crompton, Rookes Evelyn Bell, Arc Works, Chelmsford; and Mansion House Buildings, Queen Victoria Street, London, E.C. [*Crompton, Chelmsford.*]

1884. Crook, Charles Alexander, Telegraph Construction and Maintenance Works, Enderby's Wharf, East Greenwich, London, S.E.

1881. Crosland, James Foyell Lovelock, Chief Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1891. Crosland, Joseph, Messrs. Seebohm and Dieckstahl, Dannemora Steel Works, Sheffield; and Stanley Avenue, Birkdale, Southport.

1865. Cross, James, Messrs. John Hutchinson and Co., Alkali Works, Widnes; and Eirianfa, Llangollen.

1875. Crossley, William John, Messrs. Crossley Brothers, Great Marlborough Street, Manchester. [*Crossleys, Openshaw.*]

1882. Cruickshank, William Douglass, Chief Government Engineer Surveyor, Marine Board, Sydney, New South Wales.

1889. Cullen, William Hart, Resident Engineer, The Aluminium Co., Oldbury, near Birmingham.

1887. Cutler, George Benjamin, Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E.; and 4 Westcombe Park, Blackheath, London, S.E.

1876. Cutler, Samuel, Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E. [*Cutler, Millwall.* 5059.]; and 16 Great George Street, Westminster, S.W.

1888. Dadabhoy, Cursetjee, Messrs. Shapurji Sorabji and Co., Bombay Foundry and Engine Works, Khetwady, Bombay, India; and Cumbala Hill, Bombay, India.

1864. Daglish, George Heaton, Rock Mount, St. Anne's Road, Aigburth, near Liverpool. [*Daglish, Aigburth.* 2717.]

1891. Daglish, Harry Bolton, Messrs. Robert Daglish and Co., St. Helen's Engine and Boiler Works, St. Helen's, Lancashire.

1883. D'Albert, Charles, Société des Anciens Établissements Hotchkiss et Cie., 6 Route de Gonesse, St. Denis, Seine, France.

1890. Dalby, William Ernest, Engineering Department, The University, Cambridge.

1889. Dalgarno, James Robert, Danesford, Countess Wells Road, Mannofield, Aberdeen.

1893. Dall, John, Messrs. Harland and Wolff, Belfast.

1893. Dalrymple, Alexander, Superintendent Engineer, Hall Line of Steamers, 19 Tower Buildings N., Water Street, Liverpool.

1881. D'Alton, Patrick Walter, London Electric Supply Corporation, Stowage Wharf, Deptford, London, S.E.

1866. Daniel, Edward Freer, Messrs. Worthington and Co., The Brewery, Burton-on-Trent; and 89 Derby Street, Burton-on-Trent.

1866. Daniel, William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds; and Fern Bank, Horsforth, Leeds.

1891. Daniels, Thomas, Messrs. Nasmyth Wilson and Co., Patricroft, Manchester.

1888. Darbishire, James Edward, 110 Cannon Street, London, E.C. [*Ezra, London.* 11306.]

1878. Darwin, Horace (*Life Member*), The Orchard, Huntingdon Road, Cambridge.

1873. Davey, Henry, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds [*Sun Foundry, Leeds*]; and 3 Prince's Street, Westminster, S.W.

1888. Davidson, Samuel Cleland, Sirocco Works, Bridge End, Belfast.

1880. Davies, Charles Merson, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow; and Laurieville, Queen's Drive, Crosshill, Glasgow.

1885. Davies, Edward John Mines, 24 Harrington Square, London, N.W.

1891. Davies, John Hubert, P.O. Box 455, Johannesburg, Transvaal, South Africa.

1894. Davis, George, Engineer's Office, Lancashire and Yorkshire Railway, Hunt's Bank, Manchester.

1868. Davis, Henry Wheeler, 5 Highbury Grove, Highbury, London, N.

1877. Davison, John Walter, Bombay Baroda and Central India Railway, Ahmedabad, India: (or care of Mrs. Channon, 23 Streatley Road, Brondesbury, London, N.W.)

1884. Davison, Robert, Locomotive Department, Caledonian Railway, St. Rollox, Glasgow.

1873. Davy, David, Messrs. Davy Brothers, Park Iron Works, Sheffield. [*Motor, Sheffield.*]

1892. Davy, William James, 161 Huddleston Road, Tufnell Park, London, N.

1883. Daw, James Gilbert, Messrs. Nevill Druce and Co., Llanelly Copper Works, Llanelly.

1874. Daw, Samuel, 50 Chelsea Road, Southsea, Portsmouth.

1879. Dawson, Bernard, 110 Cannon Street, London, E.C. [*Crocus, London.*]; and The Laurels, Malvern Link, Malvern. [*Heather, Malvern Link.*]

1875. Dawson, Edward, 2 Windsor Place, Cardiff. [*Mechanical, Cardiff.*]

1890. Day, George Cameron, Messrs. Day Summers and Co., Northam Iron Works, Southampton.

1886. Dayson, William Ogden, Blaenavon Works, Blaenavon, R.S.O., Monmouthshire.

1874. Deacon, George Frederick, 32 Victoria Street, Westminster, S.W.

1880. Deacon, Richard William, Messrs. Samuel Fisher and Co., Nile Foundry, Birmingham; and 16 Carpenter Road, Edgbaston, Birmingham.

1894. Deakin, Benjamin Walter, Resident Engineer, City of London Electric Lighting Station, 64 Bankside, Southwark, London, S.E.

1868. Dean, William, Locomotive Superintendent, Great Western Railway, Swindon.

1887. Deas, James, Clyde Navigation, Glasgow.

1866. Death, Ephraim, Messrs. Death and Ellwood, Albert Works, Leicester.

1884. Decauville, Paul, Portable Railway Works, Petit Bourg, Seine-et-Oise, France. [*Decauville, Corbeil.*]

1890. Deeley, Richard Mountford, Locomotive Department, Midland Railway, Derby; and 10 Charnwood Street, Derby.

1877. Dees, James Gibson, 36 King Street, Whitehaven.

1889. Defries, Wolf, Messrs. Defries and Sons, 147 Houndsditch, London, E. [*Defries, London.*]

1882. Denison, Samuel, Messrs. Samuel Denison and Son, Old Grammar School Foundry, North Street, Leeds. [*Weigh, Leeds.* 221.]

1892. Dennis, George D., Superintendent Engineer to William Whiteley, 147 Queen's Road, London, W.

1888. Dent, Charles Hastings, London and North Western Railway, Lime Street Station, Liverpool.

1883. Dick, Frank Wesley, Palmers Shipbuilding and Iron Works, Jarrow.

1891. Dick, John Norman, Government Marine Surveyor, Penang, Straits Settlements.

1890. Dickinson, Alfred, Engineer, South Staffordshire Tramways, Darlaston, Wednesbury.

1891. Dickinson, James Clark, Palmer's Hill Engine Works, Sunderland.

1880. Dickinson, John, Palmer's Hill Engine Works, Sunderland. [*Bede, Sunderland.*]

1892. Dickinson, Richard Elihu, Bowling Iron Works, Bradford.

1892. Dickinson, Richard Henry, Locomotive Superintendent, Birmingham Central Tramways, Kyotts Lake Depôt, Birmingham.

1875. Dickinson, William, Warham Road, Croydon.

1888. Dickson, George Manners, Assistant Engineer, Calcutta Water Works, Municipal Office, Calcutta, India.

1886. Dixon, Robert, 10 Claremont Street, Newcastle-on-Tyne.

1883. Dixon, Samuel, Messrs. Kendall and Gent, Victoria Works, Springfield, Salford, Manchester. [*Tools, Manchester.* Nat. 330; Mutual 1330.]

1887. Dixon, William Basil, Earle's Shipbuilding and Engineering Works, Hull.

1872. Dobson, Benjamin Alfred, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton. [*Dobsons, Bolton.*]

1873. Dobson, Richard Joseph Caistor, De Volharding, Soerabaya, Java: (or care of Miss Dobson, 4 Chesterfield Buildings, Victoria Park, Clifton, Bristol.)

1880. Dodd, John, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1868. Dodman, Alfred, Highgate Foundry, Lynn. [*Dodman, Lynn.*]

1889. Dolby, Ernest Richard, 8 Prince's Street, Westminster, S.W.

1880. Donald, James, Superintendent Engineer, Messrs. James Fisher and Sons, Fisher's Buildings, Barrow-in-Furness.

1876. Donaldson, John, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.; and Tower House, Turnham Green.

1873. Donkin, Bryan (*Life Member*), Messrs. B. Donkin and Co., Southwark Park Road, Bermondsey, London, S.E.

1891. Donovan, Edward Wynne, Messrs. J. S. Leach and Co., Mount Street Works, Harpurhey, Manchester.

1865. Douglas, Charles Prattman, Thornbeck Hill, Carmel Road, Darlington.

1879. Douglass, Sir James Nicholas, F.R.S., Stella House, Dulwich, London, S.E.

1879. Douglass, William, Chief Engineer to the Commissioners of Irish Lights, Westmoreland Street, Dublin.

1891. Douglass, William James, Messrs. Douglass Brothers, Globe Iron Works, Blaydon-on-Tyne, R.S.O., County Durham.

1887. Douglass, William Tregarthen, 15 Victoria Street, Westminster, S.W.

1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Engine and Iron Works, Carlisle; and Viewfield, Stanwix, near Carlisle.

1873. Dove, George, Redbourn Hill Iron and Coal Co., Frodingham, near Doncaster [*Redbourn, Frodingham.*]; and Hatfield House, Hatfield, near Doncaster.

1866. Downey, Alfred C., Messrs. Downey and Co., Coatham Iron Works, Middlesbrough; and Belle Vue, Marton Road, Middlesbrough.

1881. Dowson, Joseph Emerson, 3 Great Queen Street, Westminster, S.W. [*Gaseous, London.*]

1880. Doxford, Robert Pile, Messrs. William Doxford and Sons, Pallion Shipbuilding and Engine Works, Sunderland.

1874. Dredge, James, 35 Bedford Street, Strand, London, W.C. [3663.]

1890. Drewet, Tom, Government Senior Inspector of Steam Boilers, Town Custom House, Bombay, India.

1886. Drummond, Dugald, Messrs. D. Drummond and Son, Glasgow Railway Engineering Works, Helen Street, Govan, Glasgow. [*Expansion, Glasgow.* 1699.]

1889. Drummond, Richard Oliver Gardner, P.O. Box 92, Johannesburg, Transvaal, South Africa.

1877. Dübs, Charles Ralph, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1885. Duckering, Charles, Water Side Works, Rosemary Lane, Lincoln.

1880. Duckham, Frederic Eliot, Engineer, Millwall Docks, London, E.

1868. Dugard, William Henry, Messrs. Dugard Brothers, Vulcan Rolling Mills, Bridge Street West, Summer Lane, Birmingham. [*Vulcan, Birmingham.*]

1879. Duncan, David John Russell, Messrs. Duncan Brothers, 28 Victoria Street, Westminster, S.W. [*Doucine, London.*]; and Kilmux, Leven.

1886. Duncan, Norman, Mechanical Engineer to the Municipality, Rangoon, British Burmah, India.

1894. Dunell, George Robert, 36 Bedford Street, Strand, London, W.C.; and 9 Grove Park Terrace, Chiswick, London, W.

1892. Dunlop, James, Victoria Jubilee Technical Institute, Byculla, Bombay, India.

1870. Dunlop, James Wilkie, 39 Delancey Street, Regent's Park, London, N.W.

1881. Dunn, Henry Woodham, Charlcombe Grove, Lansdown, Bath.

1890. Dunn, Hugh Shaw, Engineer, Caprington Collieries, Kilmarnock.

1885. Durham, Frederick William, 27 Leadenhall Street, London, E.C. [*Oilring, London.*]; and Glemham Lodge, New Barnet.

1886. Duvall, Charles Anthony, Messrs. E. Bennis and Co., Lancashire Stoker Works, Deansgate Foundry, Bolton.

1887. Dymond, George Cecil, Messrs. W. P. Thompson and Co., 6 Lord Street, Liverpool.

1865. Dyson, Robert, Messrs. Owen and Dyson, Rother Iron Works, Rotherham.

1880. Eager, John Edward, Messrs. William Crichton and Co., Engineering and Shipbuilding Works, Abo, Finland.

1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.

1858. Easton, Edward, 11 Delahay Street, Westminster, S.W.

1884. Eastwood, Charles, Manager, Linacre Gas Works, Liverpool.

1892. Eastwood, Thomas Carline, Messrs. Eastwood Swingler and Co., Victoria and Railway Iron Works, Derby. [*Swingler, Derby.*]

1888. Eaton-Shore, George, Borough Engineer, Temple Chambers, Crewe.

1875. Eaves, William, Engineer, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.

1878. Eckart, William Roberts, Messrs. Salkeld and Eckart, 632 Market Street, P. O. Box 1844, San Francisco, California, United States.

1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1886. Ede, Francis Joseph, Messrs. Ede Brothers, Silchar, Cachar, India.

1893. Eden, The Hon. Francis Fleetwood, Los Talleres de Sola, Ferro Carril del Sud, Buenos Aires, Argentine Republic: (or Edenthorpe, Doncaster.)

1887. Edlin, Herbert William, P.O. Box 199, Cape Town, Cape Colony: (or The Limes, Ellerton Road, Surbiton, R. O., Kingston-on-Thames.)

1883. Edmiston, James Brown, Marine Superintending Engineer, Messrs. Hamilton Fraser and Co., K Exchange Buildings, Liverpool; and Ivy Cottage, Highfield Road, Walton, Liverpool.

1871. Edwards, Edgar James, 42 Rye Hill Park, Peckham, London, S.E.

1877. Edwards, Frederick, 62 Bishopsgate Street Within, London, E.C.

1888. Ellery, Henry George, 7 Fernbank Road, Redland, Bristol.

1875. Ellington, Edward Bayzand, Hydraulic Engineering Works, Chester; and Hydraulic Engineering Co., Palace Chambers, 9 Bridge Street, Westminster, S.W.

1892. Elliott, Archibald Campbell, D.Sc., Professor of Engineering, University College of South Wales and Monmouthshire, Cardiff.

1883. Elliott, Henry John, Assistant Manager, Elliott's Metal Works, Selly Oak, near Birmingham. [*Elmeco, Birmingham.*]

1869. Elliott, Henry Worton, Selly Oak Works, near Birmingham. [*Elmeco, Birmingham.*]

1882. Elliott, Thomas Graham, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1892. Ellis, Joseph S., Central Engineering Works, Chepstow [*Engineer, Chepstow.*]; and Myrtle Cottage, Chepstow.

1880. Ellis, Oswald William, 6 Grosvenor Place, Jesmond, Newcastle-on-Tyne. [*Robey, Newcastle-on-Tyne.*]

1885. Elsworthy, Edward Houtson, Messrs. Richardson and Cruddas, Byculla Iron Works, Bombay, India; and Altamont Road, Cumbala Hill, Bombay, India.

1875. Elwell, Thomas, 223 Avenue de Paris, Plaine St. Denis, Seine, France.

1878. Elwin, Charles, London County Council, Spring Gardens, London, S.W.

1890. English, Lt.-Colonel Thomas, General Manager, Palmer's Shipbuilding and Iron Works, Jarrow [*Palmers, Jarrow.*]: (or care of W. Stamm, 17 Billiter Buildings, Billiter Street, London, E.C.)

1894. English, Thomas Matthew, Superintendent, Die and Coining Department, H. M. Mint, Bombay, India.

1894. Ennor, Charles John, 55 Rua da Reboleira, Oporto, Portugal.

1885. Errington, William, Salisbury Buildings, Bourke Street, Melbourne, Victoria.

1890. Esson, John, Chatteris Engineering Works, Chatteris, S.O., Cambridgeshire.

1889. Etches, Harry, 17 Napoleon Street, Brantford, Ontario, Canada.

1884. Etherington, John, 39A King William Street, London Bridge, London, E.C.

1887. Evans, Arthur George, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1884. Evans, David, Messrs. Bolckow Vaughan and Co., Cleveland Iron and Steel Works, South Bank, R.S.O., Yorkshire.

1892. Evanson, Frederic Macdonnell, Engineer and Manager, Manchester Corporation Hydraulic Pumping Station, Gloucester Street, Manchester.

1887. Everard, John Breedon, 6 Millstone Lane, Leicester.

1887. Everitt, Nevill Henry, Messrs. Thomas Piggott and Co., Atlas Works, Birmingham; and Ardendale, Knowle, Warwickshire.

1881. Ewen, Thomas Buttwell, Messrs. Ewen and Mitton, Smithfield Works, Sherlock Street, Birmingham.

1891. Ewing, James Alfred, F.R.S., Professor of Mechanism and Applied Mechanics, Engineering Department, The University, Cambridge; and Langdale Lodge, Cambridge.

1890. Exton, George Gaskell, Messrs. Chubb and Son, 128 Queen Victoria Street, London, E.C.

1868. Fairbairn, Sir Andrew, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds; and Askham Richard, York.

1875. Farcot, Jean Joseph Léon, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1880. Farcot, Paul, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1881. Farrar, Sidney Howard, Messrs. Howard Farrar and Co., Port Elizabeth, South Africa; and care of Messrs. F. A. Robinson and Co., 54 Old Broad Street, London, E.C.

1882. Fawcett, Thomas Constantine, White House Engineering Works, Leeds. [*Fawcett, Leeds.*]

1882. Feeny, Victor Isidore, 60 Queen Victoria Street, London, E.C. [*Victor Feeny, London.*]

1876. Fell, John Corry, 1 Queen Victoria Street, London, E.C.; and Excelsior Works, Old Street, London, E.C.

1869. Fenwick, Clennell, Victoria Docks Engine Works, Victoria Docks, London, E. [*Clennell, London.*]

1892. Fenwick, James, 19 Bridge Street, Sydney, New South Wales. [1038.]

1870. Ferguson, Henry Tanner, Wolleigh, Bovey Tracey, near Newton Abbot.

1881. Ferguson, William, Harbour Board, Wellington, New Zealand: (or care of Montgomery Ferguson, 81 James Street, Dublin.)

1866. Fiddes, Walter, Clapton Villa, Belgrave Road, Tyndall's Park, Bristol.

1867. Field, Edward, 4 Trafalgar Square, London, W.C.

1888. Field, Howard, 12 London Street, Fenchurch Street, London, E.C.

1884. Fielden, Joseph Petrie, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.

1874. Fielding, John, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester. [*Atlas, Gloucester.*]

1891. Finlayson, Finlay, East End Villa, Lugar Street, Coatbridge.

1891. Firth, George Henry, 2 Mavesyn Place, Fairfield, Manchester.

1888. Fischer, Gustave Joseph, Railway Construction Branch, Public Works Department, Sydney, New South Wales; and Oakhurst, West Street, North Sydney, New South Wales.

1889. Fisher, Henry Bedwell, Marine Shops, London Brighton and South Coast Railway, Newhaven, Sussex.

1884. Fisher, Henry Oakden, Ty Mynydd, Radyr, near Cardiff.

1888. FitzGerald, Maurice Frederick, Professor of Engineering, Queen's College, Belfast.

1877. Flannery, James Fortescue, 9 Fenchurch Street, London, E.C. [2283.]

1883. Fletcher, George, Masson and Atlas Works, Litchurch, Derby.

1872. Fletcher, Herbert, Ladyshore Colliery, Little Lever, Bolton; and The Hollins, Bolton.

1867. Fletcher, Lavington Evans, Chief Engineer, Manchester Steam Users' Association, 9 Mount Street, Albert Square, Manchester. [*Steam Users', Manchester.*]

1892. Focken, Charles Frederick, Messrs. Apcar and Co., Raddah Bazar, Calcutta, India; and care of Institute of Engineers and Shipbuilders, Hong Kong, China.

1859. Fogg, Robert, 159 Knight's Hill, West Norwood, London, S.E.

1887. Foley, Nelson, Engineering Manager, Società Industriale Napoletana Hawthorn-Guppy, Naples, Italy.

1886. Folger, William Mayhew, Commander, United States Navy, Bureau of Ordnance, Naval Department, Washington, D.C., United States.

1877. Forbes, Daniel Walker, Smithfield Works, New Road, Blackwall, London, E.

1882. Forbes, David Moncur, Engineer, H. M. Mint, Bombay.

1892. Forbes, Percy Alexander, Messrs. Lambert Brothers, Tube Mills, Iron and Brass Works, Walsall.

1882. Forbes, William George Loudon Stuart, Superintendent of General Workshops, H. M. Mint, Calcutta.

1892. Forrest, Hilary Sheldon, General Manager, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton.

1888. Forster, Alfred Llewellyn, Assistant Engineer, Newcastle and Gateshead Water Works, Newcastle-on-Tyne.

1888. Forster, Edward John, Malta Villa, West Smethwick, Birmingham.

1882. Forsyth, Robert Alexander, Courtway, Gold Tops, Newport, Monmouthshire.

1889. Foster, Ernest Howard, Messrs. Henry R. Worthington, 86 Liberty Street, New York, United States.

1889. Foster, Herbert Anderton (*Life Member*), Messrs. John Foster and Son, Black Dike Spinning Mills, Queensbury, near Bradford.

1888. Foster, James, Lily Bank, St. Andrew's Drive, Pollokshields, Glasgow.

1884. Foster, John Slater, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1882. Fothergill, John Reed, Consulting Engineer, Dock Office, West Hartlepool; and 1 Bathgate Terrace, West Hartlepool.

1877. Foulis, William, Manager, Glasgow Corporation Gas Department, City Chambers, 45 John Street, Glasgow.

1885. Fourny, Hector Foster, French Chambers, Queen's Dock-Side, Hull. [*Veritas, Hull.*]

1866. Fowler, George, Basford Hall, near Nottingham.

1847. Fowler, Sir John, Bart., K.C.M.G., 2 Queen Square Place, Westminster, S.W.

1894. Fowler, Robert Henry, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds. [*Fowler, Leeds.*]

1885. Fowler, William Henry, 6 Victoria Station Approach, Manchester; and Calderbank Avenue, Flixton, near Manchester.

1866. Fox, Sir Douglas, 28 Victoria Street, Westminster, S.W.

1875. Fox, Samson, Leeds Forge, Leeds.

1884. Frampton, Edwin, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E. [*Oxygen, London.* 8007.]

1888. Francken, William Augustus, care of Messrs. Grindlay and Co., 55 Parliament Street, London, S.W.

1885. Franki, James Peter, Morts Dock and Engineering Co., Morts Bay, Sydney, New South Wales: (or care of Messrs. Goldsbrough Mort and Co., 149 Leadenhall Street, London, E.C.)

1877. Fraser, John Hazell, Messrs. John Fraser and Son, Millwall Boiler Works, London, E.; and 110 Cannon Street, London, E.C.

1888. Frenzel, Arthur Benjamin, 318 W. 135th Street, New York, United States.

1891. Frier, John Drummond, Ivy Villa, 6 Griffin Road, Plumstead.

1876. Frost, William, Manager, Carlisle Steel and Engine Works, Sheffield; and Barnsley Road, Sheffield.

1866. Fry, Albert, Bristol Wagon Works, Lawrence Hill, Bristol.

1891. Fuller, Charles Frederick, 171 Queen Victoria Street, London, E.C.

1884. Furness, Edward, Knollcroft, Knoll Road, Bexley, S.O., Kent.

1890. Gadd, William, Assistant Locomotive Engineer, Waterford and Limerick Railway, Limerick.

1866. Galloway, Charles John, Managing Director, Messrs. Galloways, Knott Mill Iron Works, Manchester. [*Galloway, Manchester.*]

1862. Galton, Sir Douglas, K.C.B., D.C.L., F.R.S., 12 Chester Street, Grosvenor Place, London, S.W.

1884. Ganga Ram, Rai Bahadur, Executive Engineer, Public Works Department, Amritsar, Punjaub, India: (or care of Messrs. Thomas Wilson and Co., 24 Rood Lane, London, E.C.)

1891. Garrard, Charles Riley, Usine Gladiator, Pré St. Gervais (Seine), France.

1882. Garrett, Frank, Messrs. Richard Garrett and Sons, Leiston Works, Leiston, R.S.O., Suffolk. [*Garrett, Leiston.*]

1894. Gatehouse, Tom Ernest, 22 Paternoster Row, London, E.C. [*Ageekay, London.*]

1867. Gauntlett, William Henry, 33 Albert Terrace, Middlesbrough. [*Pyrometer, Middlesbrough.*]

1888. Gaze, Edward Henry James, 4 Victoria Drive, Mount Florida, Glasgow.

1888. Geddes, Christopher, 2A Drury Buildings, Water Street, Liverpool. [*Graccius, Liverpool.*]

1880. Geoghegan, Samuel, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin. [*Guinness, Dublin.*]

1887. Gibb, Andrew, Managing Engineer, Messrs. Rait and Gardiner, Millwall Docks, London, E.; and 30 South Street, Greenwich, London, S.E.

1871. Gibbins, Richard Cadbury, Berkley Street, Birmingham. [*Gibbins, Birmingham.*]

1883. Gilchrist, Percy Carlyle, F.R.S. (*Life Member*), Palace Chambers, 9 Bridge Street, Westminster, S.W. [*Gilchrist, London*]; and Frognal Bank, Finchley New Road, Hampstead, London, N.W.

1856. Gilkes, Edgar, Westholme, Grange-over-Sands, viâ Carnforth, Lancashire.

1880. Gill, Charles, Messrs. Young and Gill, Engineering Works, Java; and Java Lodge, Beckenham.

1889. Gill, Frederick Henry, Messrs. Alexander Penney and Co., 107 Fenchurch Street, London, E.C.

1884. Gimson, Arthur James, Messrs. Gimson and Co., Engine Works, Vulcan Street, Leicester. [*Gimson, Leicester.* 6.]

1881. Girdwood, William Wallace, Indestructible Packing Works, 9 Lea Place, East India Dock Road, Poplar, London, E.

1874. Gjers, John, Messrs. Gjers Mills and Co., Ayresome Iron Works, Middlesbrough.

1887. Gledhill, Manassah, Sir Joseph Whitworth and Co., Openshaw, Manchester.

1880. Godfrey, William Bernard, 23 St. Swithin's Lane, London, E.C.

1888. Goff, John, Messrs. Salt and Co., The Brewery, Burton-on-Trent.

1882. Goldsmith, Alfred Joseph, Lillington, Moray Street, New Farm, Brisbane, Queensland.

1877. Goodbody, Robert, Messrs. Goodbody, Clashawaun Jute Factory, Clara, near Moate, Ireland.

1869. Goodeve, Thomas Minchin, 5 Crown Office Row, Temple, London, E.C.

1875. Goodfellow, George Ben, Messrs. Goodfellow and Matthews, Hyde Iron Works, Hyde, near Manchester. [*Goodfellow, Hyde.*]

1890. Goodman, John, Professor of Engineering, Yorkshire College, Leeds.

1889. Goold, William Tom, 39 Queen Victoria Street, London, E.C.; and The Glen, Gorst Road, Wandsworth Common, London, S.W.

1865. Göransson, Göran Fredrick, Sandvik Iron Works, near Gefle, Sweden: (or care of James Bird, 118 Cannon Street, London, E.C.)

1887. Gordon, Alexander, Niles Tool Works, and Messrs. Gordon and Maxwell, Hamilton, Ohio, United States.

1888. Gore, Arthur Saunders, Sherborne Metal Works, Sherborne Street, Birmingham.

1879. Gorman, William Augustus, Messrs. Siebe and Gorman, 187 Westminster Bridge Road, London, S.E. [*Siebe, London.*]

1880. Gottschalk, Alexandre, 13 Rue Auber, Paris.

1877. Goulty, Wallis Rivers, Messrs. Wheatley Kirk, Price, and Goulty, Albert Chambers, Albert Square, Manchester. [*Indicator, Manchester.*]

1887. Gourlay, Charles Gershom, Messrs. Gourlay Brothers and Co., Dundee Foundry, Dundee.

1890. Grace, Robert William, Colorado Fuel and Iron Co., Pueblo, Colorado, United States.

1878. Grafton, Alexander, Vulcan Works, Bedford. [*Grafton, Bedford.*]

1886. Grant, Percy, Sola Works, Ferro Carril del Sud, Buenos Aires, Argentine Republic: (or care of John M. Grant, 136 Sutherland Avenue, Maida Vale, London, W.)

1891. Gray, George Macfarlane (*Life Member*), Imperial Chinese Customs, Hong Kong, China; and 1 Claremont Road, Forest Gate, London, E.

1865. Gray, John Macfarlane, Chief Examiner of Engineers, Marine Department, Board of Trade, 79 Mark Lane, London, E.C.; and 1 Claremont Road, Forest Gate, London, E. [*Yarg, London.*]

1876. Gray, John William, Engineer, Corporation Water Works, Broad Street, Birmingham.

1879. Gray, Thomas Lowe, Lloyd's Register, 2 White Lion Court, Cornhill, London, E.C.; and 24 St. Michael's Road, Stockwell, London, S.W.

1879. Greathead, James Henry, 15 Victoria Street, Westminster, S.W.

1861. Green, Sir Edward, Bart., Messrs. E. Green and Son, Phœnix Works, Wakefield.

1888. Green, Henry Joseph Kersting, Messrs. Barry and Co., 5 Lyons Range, Calcutta, India; 13 Garden Reach, Calcutta, India: (or care of Messrs. J. B. Barry and Son, 110 Cannon Street, London, E.C.)

1893. Green, William Penrose, Messrs. Thomas Green and Son, Smithfield Iron Works, Leeds.

1871. Greener, John Henry, 15 Walbrook, London, E.C.

1878. Greenwood, Arthur, Messrs. Greenwood and Batley, Albion Works, Leeds.

1874. Greenwood, William Henry (*Life Member*), Birmingham Small Arms and Metal Co., Adderley Park Works, Birmingham.

1894. Gregory, Horace Mark, Messrs. Brown, Lenox and Co., 9 Martin's Lane, Cannon Street, London, E.C.

1879. Grenville, Robert Neville, Butleigh Court, Glastonbury.

1892. Gresham, Harry Edward, Messrs. Gresham and Craven, Craven Iron Works, Salford, Manchester. [*Brake, Manchester.* 613.]

1880. Gresham, James, Messrs. Gresham and Craven, Craven Iron Works, Salford, Manchester. [*Brake, Manchester.* 613.]

1883. Grew, Frederick, Halton, 90 Ritherdon Road, Upper Tooting, London, S.W.

1874. Grew, Nathaniel, Dashwood House, 9 New Broad Street, London, E.C.

1884. Griffiths, James E., Messrs. Griffiths and James, 2 Bute Crescent, Cardiff.

1873. Griffiths, John Alfred, Shirecliffe, New South Head Road, Sydney, New South Wales: (or care of Thomas Griffiths, Alderley Edge, Manchester.)

1889. Grimshaw, James Walter, Resident Engineer, Harbours and Rivers Department, Sydney, New South Wales; and Australian Club, Sydney, New South Wales.

1891. Groom, Richard Alfred, Shropshire Works, Wellington, Salop.

1879. Grose, Arthur, Messrs. Grose Norman and Co., Reliance Works, Northampton.

1886. Grove, David, 24 Friedrich Strasse, Berlin.

1870. Guilford, Francis Leaver, Messrs. G. R. Cowen and Co., Beck Works, Brook Street, Nottingham. [*Cowen, Nottingham.* 87.]

1884. Gulland, James Ker, Diamond Drill Co., 8 Victoria Street, Westminster, S.W. [*Gulland, London.*]

1886. Guy, Charles Williams, 123 Oakfield Road, Penge, London, S.E.

1870. Gwynne, James Eglinton Anderson (*Life Member*), Brooke Street Works, Holborn, London, E.C. [*Gwynnegram, London.*]

1870. Gwynne, John, Hammersmith Iron Works, Hammersmith, London, W.; and 89 Cannon Street, London, E.C.

1888. Hadfield, Robert Abbott, Hecla Foundry Steel Works, Sheffield. [*Hadfield, Sheffield.*]

1894. Haigh, Noel Newall, Messrs. W. B. Haigh and Co., Globe Iron Works, Plane Street, Oldham.

1884. Hall, Albert Francis, George F. Blake Manufacturing Co., 111 Federal Street, Boston; and 3 Cordis Street, Charlestown, Boston, Massachusetts, United States.

1892. Hall, George Edward, Mechanical Superintendent, Lighting Department, Salford Corporation, Wilburn Street, Salford, Manchester.

1894. Hall, Henry Platt, Messrs. Platt Brothers and Co., Hartford New Works, Oldham.

1879. Hall, John Francis, Norbury, Pittsmoor, Sheffield.

1881. Hall, John Percy, Managing Director, Messrs. John Penn and Sons. Greenwich, London, S.E.

1882. Hall, John Willim, Ivy House, Bilston.

1890. Hall, Oscar Standring, Messrs. Robert Hall and Sons, Hope Foundry, Bury, Lancashire.

1874. Hall, Thomas Bernard, 119 Colmore Row, Birmingham; and Ingleside, Sandon Road, Edgbaston, Birmingham.

1871. Hall, William Silver, 9A Tsukiji, Tokyo, Japan: (or care of Messrs. Takata and Co., 88 Bishopsgate Street Within, London, E.C.)

1889. Hall-Brown, Ebenezer, Messrs. Hall-Brown Buttery and Co., Helen Street Engine Works, Govan, Glasgow. [*Triple, Glasgow.* 1843.]

1880. Hallett, John Harry, 123 Bute Street, Cardiff. [*Consulting, Cardiff.*]

1871. Halpin, Druitt, 17 Victoria Street, Westminster, S.W. [*Halpin, London.* 3075, care of Victoria Chambers Co.]

1894. Hamer, Walter, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton. [*Dobsons, Bolton.*]

1894. Hamilton, Robert, Superintendent Engineer, Khye Ho Foundry Co., Penang, Straits Settlements.

1875. Hammond, Walter John, The Grange, Knockholt, near Sevenoaks.

1886. Hanbury, John James, Edgeley, Walm Lane, Willesden Park, London, N.W.

1870. Hannah, Joseph Edward, Castle View, Carlisle.

1892. Hansell, Robert Blackwell, Baltimore, Maryland, United States: (or care of James Hansell, 62 Jerningham Road, New Cross, London, S.E.)

1888. Harada, Torazo, Superintending Engineer, Osaka Shipping Co., Osaka, Japan.

1891. Harcourt, Otto Simon Henry, Clarence Iron Works, Leeds.

1894. Harding, James Cooper, Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1888. Harding, Thomas Walter, Tower Works, Leeds.

1874. Harding, William Bishop, IX Ker. Rakos utcza 5 ik. sz., 1sö. Emelet, Budapest, Hungary.

1881. Hardingham, George Gatton Melhuish, 191 Fleet Street, London, E.C. [*Hardingham, London.*]

1883. Hardy, John George, 13 Riemergasse, Stadt, Vienna.
1869. Harfield, William Horatio, Mansion House Buildings, Queen Victoria Street, London, E.C.
1887. Hargraves, Richard, 3 London Road, Blackburn.
1887. Hargreaves, John Henry, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton.
1888. Harker, William, Messrs. Richard Schram and Co., 17A Great George Street, Westminster, S.W.
1888. Harland, Sir Edward James, Bart., M.P., Messrs. Harland and Wolff, Belfast; and Baroda House, Kensington Palace Gardens, London, W.
1894. Harmer, Oscar, Babcock and Wilcox Boiler Works, Kilbowie, Glasgow.
1891. Harris, Gordon, Messrs. Merryweather and Sons, Fire-Engine Works, Greenwich Road, London, S.E.
1879. Harris, Henry Graham, Messrs. Bramwell and Harris, 5 Great George Street, Westminster, S.W. [*Wellbram, London.* 3060.]
1885. Harris, John Henry, Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C. [*Tuneharp, London.*]
1873. Harris, Richard Henry, 63 Queen Victoria Street, London, E.C.; and Oak Hill, Surbiton, R.O., near Kingston-on-Thames.
1877. Harris, William Wallington, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.; and 24 Alexandra Villas, Hornsey Park, London, N.
1892. Harrison, Abraham Wyke, Lion Street, Abergavenny.
1885. Harrison, Frederick Henry, Lincoln Malleable Iron Works, Lincoln. [*Malleable, Lincoln.*]
1888. Harrison, George, 21 Hillsboro Road, East Dulwich, London, S.E.
1889. Harrison, Gilbert Harwood, Captain R.E., Kasr el Nil Barracks, Cairo, Egypt.
1885. Harrison, Joseph, Royal College of Science, Exhibition Road, South Kensington, London, S.W.
1891. Harrison, Joseph Hutchinson, Messrs. Howson and Harrison, 2 Exchange Place, Middlesbrough; and Clifford Villa, Coatham, Redcar.
1887. Harrison, Thomas Henry, Messrs. Davey Paxman and Co., 78 Queen Victoria Street, London, E.C.
1894. Harrison, William John, Locomotive Superintendent, Cia. Paulista, Rio Claro, São Paulo, Brazil.
1890. Harrison, William Robert, Messrs. Harrison, Bilton and Sharp, Bank Chambers, Land of Green Ginger, Hull.
1883. Hart, Frederick, 36 Prospect Street, Poughkeepsie, New York, United States.
1882. Hart, Norman, 68 Inderwick Road, Stroud Green, London, N.
1872. Hartnell, Wilson, Benson's Buildings, Park Row, Leeds.

1882. Harvey, Charles Randolph, Messrs. G. and A. Harvey, Albion Machine Works, Govan, near Glasgow.

1892. Harvey, Edward Cartwright, Engineer, Geldenhuis Estate and Gold Mining Co., P. O. Box 1022, Johannesburg, Transvaal, South Africa.

1892. Harvey, Francis Haniel, Messrs. Harvey and Co., Hayle Foundry, Hayle, Cornwall.

1886. Harvey, John Boyd, North's Navigation Collieries, Tondû, near Bridgend, Glamorganshire.

1883. Harvey, Robert, 1 Palace Gate, London, W.

1878. Harwood, Robert, Soho Iron Works, Bolton.

1881. Haslam, Sir Alfred Seale, Union Foundry, Derby. [*Zero, Derby.*]

1885. Hatton, Robert James, Henley's Telegraph Works, North Woolwich, London, E.

1857. Haughton, S. Wilfred (*Life Member*), Greenbank, Carlow, Ireland.

1878. Haughton, Thomas, 110 Cannon Street, London, E.C. [*Haughnot, London.*]

1885. Haughton, Thomas James, Bell Hotel, Gloucester; and East Africa.

1892. Hawkins, Rupert Skelton, Locomotive and Carriage Department, Indian Midland Railway, Jhansi, India.

1861. Hawkins, William Bailey, 39 Lombard Street, London, E.C.

1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.

1891. Hawksley, George William, Brightside Boiler and Engine Works, Savile Street East, Sheffield. [*Hawksley, Sheffield.* 337.]

1873. Hay, James A. C., Superintending Engineer and Constructor of Shipping to the War Department, Royal Arsenal, Woolwich.

1882. Hayes, Edward, Watling Works, Stony Stratford. [*Hayes, Stony Stratford.*]

1879. Hayes, John, 55 Steep Hill, Lincoln.

1880. Hayter, Harrison, 33 Great George Street, Westminster, S.W.

1885. Head, Archibald Potter, Messrs. Jeremiah Head and Son, 47 Victoria Street, Westminster, S.W. [*Principium, London*, 3237.]; and Queen's Square, Middlesbrough.

1888. Head, Harold Ellershaw, 5 Ilchester Mansions, Kensington, London, W.

1869. Head, Jeremiah, Messrs. Jeremiah Head and Son, 47 Victoria Street, Westminster, S.W. [*Principium, London.* 3237.]; and Queen's Square, Middlesbrough.

1857. Healey, Edward Charles, 33 Norfolk Street, Strand, London, W.C.

1890. Heap, Ray Douglas Theodore, Messrs. Crompton and Co., 4 Mansion House Buildings, Queen Victoria Street, London, E.C.; and 37 Sinclair Road, Kensington, London, W.

1872. Heap, William, 1 Rumford Place, Liverpool. [*Metal, Liverpool.* 809.]

1889. Heath, George Wilson, Messrs. Heath and Co., Observatory Works, Crayford, Kent.

1888. Heatly, Harry, Messrs. Heatly and Gresham, 7 Hastings Street, Calcutta, India [*Brake, Calcutta.*]: (or Ballygunge, West Hill Road, Wandsworth, London, S.W.)

1875. Heenan, Hammersley, Messrs. Heenan and Froude, Newton Heath Iron Works, near Manchester; and The Manor House, Wilmslow, near Manchester. [*Spherical, Newton Heath.*]

1879. Hele-Shaw, Henry Selby, Professor of Engineering, University College, Liverpool.

1869. Henderson, David Marr, Engineer-in-Chief, Imperial Maritime Customs Service of China, Shanghai, China.

1883. Henderson, John Baillie, Engineer to the Queensland Government, Water Supply Department, Brisbane, Queensland.

1891. Henderson, Thomas, 6 and 8 Trueman Street, Liverpool.

1883. Henderson, William, P.O. Box 1933, Johannesburg, Transvaal, South Africa.

1888. Henning, Gustavus Charles, 726 Temple Court, 5 Beekman Street, New York, United States.

1879. Henriques, Cecil Quixam, Messrs. John H. Wilson and Co., Sandhills, Liverpool. [*Engineers, Liverpool.*]

1875. Hepburn, George, Redcross Chambers, Redcross Street, Liverpool. [*Hepburn, Liverpool.*]

1891. Hepburn, Thomas, Officiating Chief Mechanical Engineer, Small Arms Ammunition Factory, Kirkee, Poona, India.

1892. Herbert, Alfred, Machine-Tool Works, Coventry. [*Lathe, Coventry.* 52.]

1893. Herbert, Charles, 35 Queen Victoria Street, London, E.C. [*Mancunian, London.*]

1893. Herbert, George Henry, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.

1894. Herman, Benjamin Richard, Messrs. B. R. Herman and Co., McLeod Road, Karachi, India [*Herman, Karachi.*]; and 152 Sheen Road, Richmond, Surrey.

1884. Hernu, Arthur Henry, 69 Victoria Street, Westminster, S.W.

1894. Herriot, William Scott, New Amsterdam, Berbice, British Guiana.

1884. Hervey, Matthew Wilson, Assistant Engineer, West Middlesex Water Works, Hammersmith, London, W.

1879. Hesketh, Everard, Messrs. J. and E. Hall, Iron Works, Dartford. [*Hesketh, Dartford.*]

1872. Hewlett, Alfred, Haseley Manor, Warwick.

1887. Hibbert, George, Hibbert's Works, Bank Road, Gateshead.

1871. Hick, John, Mytton Hall, Whalley, near Blackburn.

1885. Hicken, Thomas, La Compañia Fabricantes Ingleses, 302 Calle Balcarce, Buenos Aires, Argentine Republic: (or care of Miss Hicken, Bourton, near Rugby.)

1894. Higginbottom, Lloyd, Messrs. Higginbottom and Mannock, Crown Iron Works, West Gorton, Manchester.

1879. Higson, Jacob, Mining Engineer, Crown Buildings, 18 Booth Street, Manchester.

1883. Hill, John Kershaw, Engineer and Manager, West Surrey Water Works, High Street, Walton-on-Thames.

1885. Hill, Robert Anderson, Royal Mint, Little Tower Hill, London, E.

1890. Hiller, Edward George, Chief Engineer, National Boiler Insurance Co., 22 St. Ann's Square, Manchester.

1882. Hiller, Henry, Consulting Engineer, National Boiler Insurance Co., 22 St. Ann's Square, Manchester; and Athelney, Stanley Road, Alexandra Park, Manchester.

1873. Hilton, Franklin, General Manager, Ebbw Vale Steel Iron and Coal Works, Ebbw Vale, R.S.O., Monmouthshire.

1887. Hindson, William, South Shore Engineering Works, Gateshead. [*Hindson, Gateshead.*]

1891. Hodge, Arthur, Trewirgie, Redruth.

1891. Hodges, Frank Grattidge, Locomotive Department, Midland Railway, Burton-on-Trent.

1870. Hodges, Petronius, 142 Burngreave Road, Sheffield.

1880. Hodgson, Charles, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W. [*Signalmen, London.* 7068.]

1889. Hodgson, George Herbert, Thornton Road, Bradford.

1892. Hodgson, Henry Edwin, Brookhouse Iron Works, Cleckheaton, S.O., Yorkshire.

1891. Hogarth, Thomas Oswald, Great Western Railway Works, Swindon.

1889. Hoggins, Alfred Farquharson, Les Fauconnaires, Guernsey.

1866. Holcroft, Thomas, Bilston Foundry, Bilston.

1886. Holden, James, Locomotive Superintendent, Great Eastern Railway, Stratford Works, London, E.

1884. Holland, Calvert Bernard, Hazel Villa, Thicket Road, Anerley, London, S.E.

1886. Hollis, Charles William, Messrs. Claringburn and Co., Liverpool Street, Nottingham.

1885. Hollis, Henry William, Whitworth House, Spennymoor.

1891. Holman, Hugh Wilson, Messrs. E. J. Caiger and Co., 77 Billiter Buildings, Billiter Street, London, E.C. [*Caiger, London.*]

1892. Holmström, Carl Albert, Maxim-Nordenfelt Guns and Ammunition Co., 32 Victoria Street, Westminster, S.W.

1883. Holroyd, John, 133 Croxted Road, West Dulwich, London, S.E.

1873. Holt, Henry Percy, 22 Chancery Lane, London, W.C.

1890. Holt, Robert, Professor of Engineering, The People's Palace Technical Schools, Mile End Road, London, E.

1890. Holt, William Procter, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1888. Homan, Harold, Messrs. Homan and Rodgers, 10 Marsden Street, Manchester. [*Namoh, Manchester.* 637.]

1890. Hooker, Benjamin, Pear Tree Court, Farringdon Road, London, E.C.

1892. Hope, John Basil, Locomotive Department, North Eastern Railway, Leeds.

1866. Hopkins, John Satchell, Jesmond Grove, Highfield Road, Edgbaston, Birmingham.

1885. Hopkinson, Charles, Werneth Chambers, 29 Princess Street, Manchester.

1894. Hopkinson, Edward, D.Sc., Messrs. Mather and Platt, Salford Iron Works, Manchester.

1856. Hopkinson, John, Inglewood, St. Margaret's Road, Bowdon, near Altrincham.

1874. Hopkinson, John, Jun., D.Sc., F.R.S., Messrs. Chance Brothers and Co., Lighthouse Works, near Birmingham; and 5 Victoria Street, Westminster, S.W. [3092.]

1877. Hopkinson, Joseph, Messrs. Joseph Hopkinson and Co., Britannia Works, Huddersfield.

1890. Hopper, Allan, Messrs. William Hopper and Co., Moscow, Russia.

1890. Hopper, James Russell, Messrs. William Hopper and Co., Moscow, Russia.

1889. Hopwood, John, Locomotive Superintendent, Argentine Great Western Railway, Mendoza, Argentine Republic.

1891. Hornbrook, Raymond Hillman, care of General Post Office, San Francisco, California.

1880. Hornsby, James, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham. [*Hornsbys, Grantham.*]

1889. Horsfield, Cooper, Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Hunslet Road, Leeds.

1891. Horsfield, Ralph, Messrs. Kirk and Horsfield, Chapel-en-le-Frith, near Stockport.

1873. Horsley, Charles, 22 Wharf Road, City Road, London, N.

1892. Horsnell, Daniel, 79 Farringdon Road, London, E.C.

1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury.

1871. Horton, George, 4 Cedars Road, Clapham Common, London, S.W.

1886. Hosgood, John Howell, Locomotive and Hydraulic Superintendent, Barry Dock and Railways, Barry, near Cardiff.

1889. Hosken, Richard, Severn Tunnel Works, Sudbrook, near Chepstow.

1873. Hoskin, Richard, 8 Norfolk Street, Sheffield.

1892. Houghton, Francis Gassiot, 17 Victoria Street, Westminster, S.W.

1866. Houghton, John Campbell Arthur, Woodside Iron Works, near Dudley.

1889. Houghton, Thomas Harry, 58 Pitt Street, Sydney, New South Wales: (or care of Messrs. James Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.) [*Expansion, Sydney.*]

1887. Houghton-Brown, Ernest, Messrs. Houghton-Brown Brothers, Kingsbury Iron Works, Ballspond, London, N.

1891. How, William Field, Mutual Life Buildings, George Street, Sydney, New South Wales. [*Alaska, Sydney.*]

1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1879. Howard, James Harold, Britannia Iron Works, Bedford; and Kempston Grange, Bedford.

1882. Howard, John William, Gloucester Wagon Works, Gloucester.

1885. Howarth, William, Manager, Oldham Boiler Works, Oldham. [*Boilers, Oldham.*]

1861. Howell, Joseph Bennett, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield. [*Howell, Sheffield.*]

1877. Howell, Samuel Earnshaw, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield. [*Howell, Sheffield.*]

1892. Howitt, James John, Messrs. Bowman Thompson and Co., Lostock Gralam, Northwich.

1882. Howl, Edmund, Messrs. Lee Howl and Co, Tipton. [*Howl, Tipton.*]

1877. Howlett, Francis, Messrs. Henry Clayton Son and Howlett, Atlas Works, Woodfield Road, Harrow Road, London, W. [*Brickpress, London.*]

1891. Hoy, Henry Albert, Locomotive Works, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1887. Hoyle, James Rossiter, Messrs. Thomas Firth and Sons, Norfolk Works, Sheffield.

1891. Hubback, Charles Arbuthnot, 9 Church Crescent, St. Albans.

1882. Hudson, John George, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton; and Glenholme, Bromley Cross, Bolton.

1884. Hudson, Robert, Gildersome Foundry, near Leeds [*Gildersome, Leeds.* 14.]; and Weetwood Mount, Headingley, near Leeds. [454.]

1893. Hudson, William, Ahmedabad, Bombay, India.

1881. Hughes, Edward William Mackenzie, 33 Renfield Street, Glasgow; and Madgefield, Helensburgh.

1867. Hughes, George Douglas, Messrs. G. D. Hughes and Son, Queen's Foundry, London Road, Nottingham.

1889. Hughes, John, Messrs. Hughes and Lancaster, 47 Victoria Street, Westminster, S.W.

1871. Hughes, Joseph, Kingston, Wareham.

1891. Hughes, Robert M., The Currie Schools, School of Engineering, Folkestone.

1892. Hullah, Arthur, Victoria Jubilee Technical Institute, Byculla, Bombay, India: (or care of Walter Hunter, 12 Chetwynd Terrace, Meadow Road, Leeds.)

1883. Hulse, Joseph Whitworth, Messrs. Hulse and Co., Ordsal Works, Regent Bridge, Salford, Manchester. [*Esluh, Manchester.*]

1864. Hulse, William Wilson, Ordsal Works, Regent Bridge, Salford, Manchester. [*Esluh, Manchester.*]

1890. Humphries, Edward Thomas, Messrs. Edward Humphries and Co., Atlas Iron Works, Pershore.

1866. Humphrys, Robert Harry, Messrs. Humphrys Tennant and Co., Deptford Pier, London, S.E.

1894. Humpidge, James Dickerson, Messrs. Humpidge, Holborow and Co., Dudbridge Iron Works, Stroud, Gloucestershire [*Humpidge, Cainscross*]; and 1 Fairview Villas, Bath Road, Stroud, Gloucestershire.

1882. Hunt, Reuben, Aire and Calder Chemical Works, Castleford, near Normanton.

1885. Hunt, Richard, Messrs. Thomas Hunt and Sons, Albion Iron Works, 132 Bridge Road West, Battersea, London, S.W.

1856. Hunt, Thomas, Egerton Mount, Heaton Chapel, R.O., Stockport.

1874. Hunt, William, Alkali Works, Lea Brook, Wednesbury; Hampton House, Wednesbury; and Aire and Calder Chemical Works, Castleford, near Normanton.

1889. Hunter, Charles Lafayette, Engineer, Bute Docks, Cardiff.

1886. Hunter, John, Messrs. Campbells and Hunter, Dolphin Foundry, Saynor Road, Hunslet, Leeds.

1877. Hunter, Walter, Messrs. Hunter and English, High Street, Bow, London, E. [*Venator, London.*]

1888. Huxley, George, 20 Mount Street, Manchester.

1885. Hyland, John Frank, Railway Contractor, São Carlos do Pinhal, Estado de São Paulo, Brazil: (or care of Messrs. Lewis and Hyland, New Rents, Ashford, Kent.)

1877. Imray, John, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C.

1882. Ingham, William, Assistant Engineer, National Boiler Insurance Co., 22 St. Ann's Square, Manchester.

1888. Ingleby, Joseph, 20 Mount Street, Manchester.

1883. Instone, Thomas, 146 Leadenhall House, Leadenhall Street, London, E.C.

1894. Iorns, Charles Risbec, Messrs. George Richards and Co., Atlantic Works, Broadheath, near Manchester.

1892. Irons, Thomas, Manager, Messrs. Hudson Brothers, Clyde Engineering Works, Granville, New South Wales.

1894. Irwin, Thomas F., Messrs. Irwin and Atkinson, 2A Tower Chambers, Old Church Yard, Liverpool. [*Irwall, Liverpool.* 2399.]

1887. Ivatt, Henry Alfred, Locomotive Engineer, Great Southern and Western Railway, Inchicore Works, near Dublin.

1887. Ivatts, Lionel Edward, Paseo Salamanca, F 2° Derecha, San Sebastian, Spain.

1884. Jacks, Thomas William Moseley, Patent Shaft Works, Wednesbury; and Woodgreen, Wednesbury.

1894. Jackson, John Broad, Messrs. Bentley and Jackson, Lodge Bank Works, Bury, Lancashire.

1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester; and Blackbrooke, Pontrilas, R.S.O., Herefordshire. [*Jacksons, Manchester.*]

1873. Jackson, Samuel, C.I.E., 23 Calverley Park, Tunbridge Wells.

1886. Jackson, Thomas, 41 Wesley Road, Armley, Leeds.

1889. Jackson, William, Thorn Grove, Mannofield, Aberdeen.

1876. Jacobs, Charles Mattathias, 88 Bishopsgate Street Within, London, E.C. [*Vexillum, London.*]

1878. Jakeman, Christopher John Wallace, Manager, Messrs. Merryweather and Sons, Tram Locomotive Works, Greenwich Road, London, S.E.

1893. James, Arthur William, Messrs. K. L. Mukerjee and Co., 19 Sukea's Lane, Calcutta, India.

1889. James, Charles William, Wheathill Lodge, Anerley, London, S.E.

1877. James, Christopher, 4 Alexandra Road, Clifton, Bristol.

1877. James, John William Henry, 28 Victoria Street, Westminster, S.W.

1889. James, Reginald William, 1 Queen Victoria Street, London, E.C.

1879. Jameson, George, Glencormac, Bray, Ireland.

1881. Jameson, John, Messrs. Jameson and Schaeffer, Akenside Hill, Newcastle-on-Tyne. [*Jameson, Newcastle-on-Tyne.* 226.]

1888. Jaques, Captain William Henry, Messrs. See and Jaques, 1 Broadway, New York, United States. [*Menudeo, New York.*]

1888. Jeejeebhoy, Piroshaw Bomanjee, 17 Church Street, Bombay, India.

1880. Jefferies, John Robert, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich.

1881. Jefferiss, Thomas, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham. [*Tangyes, Birmingham.*]

1877. Jeffreys, Edward Homer, Hawkhills, Chapel Allerton, Leeds.

1893. Jenkin, Charles Frewen, Messrs. Nettlefolds, Castle Works, Tydu, near Newport, Monmouthshire.

1894. Jenkin, Thomas Henry, Messrs. J. Jamieson and Co., Queen's Dock Chambers, Hull. [*Propeller, Hull.* 94.]

1884. Jenkins, Alfred, Wharncliffe, Victoria Road, Penarth.

1880. Jenkins, Rhys, Patent Office, 25 Southampton Buildings, London, W.C.

1892. Jenkins, William John, Albion Iron Works, Miles Platting, Manchester.

1893. Jennins, Henry Horwood, care of Edwin Oldroyd, Crown Works, Crown Street, Leeds.

1878. Jensen, Peter, 77 Chancery Lane, London, W.C. [*Venture, London.*]

1889. Jessop, George, London and Leicester Steam-Crane and Engine Works, Leicester.

1863. Johnson, Bryan, Hydraulic Engineering Works, Chester; and 9 Upper Northgate Street, Chester.

1885. Johnson, John Clarke, Messrs. James Russell and Sons, Crown Tube Works, Wednesbury.

1890. Johnson, John William, care of Baron Knoop, Grande Loubianka, Moscow, Russia.

1891. Johnson, Lacey Robert, Master Mechanic, Pacific Division, Canadian Pacific Railway, Vancouver, British Columbia.

1888. Johnson, Lawrence Potter, Assistant Locomotive Superintendent, Burma State Railway, Insein, British Burma.

1882. Johnson, Samuel, Manager, Globe Cotton and Woollen Machine Works, Rochdale; and Glebelands, Rochdale.

1887. Johnson, Samuel Henry, Engineering Works, Carpenter's Road, Stratford, London, E.; and The Warren Hill, Loughton, Essex.

1861. Johnson, Samuel Waite, Locomotive Superintendent, Midland Railway, Derby.

1888. Johnson, William, Castleton Foundry and Engineering Works, Armley Road, Leeds.

1891. Johnston, Andrew, Bank Buildings, Hong Kong, China. [*Marine, Hong Kong.*]

1872. Joicey, Jacob Gowland, Messrs. J. and G. Joicey and Co., Forth Banks West Factory, Newcastle-on-Tyne. [*Engines, Newcastle-on-Tyne.*]

1882. Jolin, Philip, 35 Narrow Wine Street, Bristol; and 2 Elmdale Road, Redland, Bristol.

1891. Jones, Charles Frederick, 85 Davenport Street, Bolton.

1871. Jones, Charles Henry, Assistant Locomotive Superintendent, Midland Railway, Derby.

1873. Jones, Edward, Broomfield House, Perry Barr, Birmingham.

1884. Jones, Felix, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1878. Jones, Frederick Robert, Superintending Engineer, Sirmoor State, Nahan, near Umballa, Punjaub, India: (or care of Messrs. Richard W. Jones and Co., Newport, Monmouthshire.)

1867. Jones, George Edward, District Locomotive Superintendent, North Western Railway, Quetta, Beluchistan, India : (or care of Mrs. Edward Jones, 9 Sydenham Villas, Cheltenham.)

1878. Jones, Harry Edward, Engineer, Commercial Gas Works, Stepney, London, E.

1881. Jones, Herbert Edward, Locomotive Department, Midland Railway, Manchester.

1890. Jones, Morlais Glasfryn, 6 Delahay Street, Westminster, S.W.
1882. Jones, Samuel Gilbert, Hatherley Court, Gloucester.
1887. Jones, Thomas, Central Board School, Deansgate, Manchester.
1872. Jones, William Richard Sumption, Whitehall Court, London, S.W.
1883. Jordan, Edward, Manager, Cardiff Junction Dry Dock and Engineering Works, Cardiff.
1891. Jordan, Henry George, Jun., Municipal Technical School, Princess Street, Manchester.
1880. Joy, David, 17 Victoria Street, Westminster, S.W.; and Manor Road House, Beckenham.
1891. Judd, Joseph Henry, Head Master, Municipal Technical School, York Place, Brighton.
1878. Jüngermann, Carl, Maschinenbau Actien Gesellschaft Vulcan, Bredow bei Stettin, Germany.
1884. Justice, Howard Rudulph, 55 and 56 Chancery Lane, London, W.C. [*Syng, London.* 2504.]

1889. Kanthack, Ralph, 21 Golden Square, Regent Street, London, W. [*Kanthack, London.*]
1888. Kapteyn, Albert, Westinghouse Brake Co., Canal Road, York Road, King's Cross, London, N.
1869. Keen, Arthur, London Works, near Birmingham. [*Globe, Birmingham.*]
1883. Keen, Francis Watkins, Patent Nut and Bolt Works, Westbromwich.
1873. Kelson, Frederick Colthurst, Angra Bank, Waterloo Park, Waterloo, near Liverpool.
1881. Kendal, Ramsey, Locomotive Department, North Eastern Railway, Darlington.
1879. Kennedy, Professor Alexander Blackie William, LL.D., F.R.S., 14 Old Queen Street, Westminster, S.W. [*Kinematic, London.*]
1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway, 45 Finsbury Circus, London, E.C.; and 29 Lupus Street, St. George's Square, London, S.W.
1892. Kennedy, Thomas, The Glenfield Engineering Works, Kilmarnock.
1868. Kennedy, Thomas Stuart, Parkhill, Wetherby.
1875. Kenrick, George Hamilton, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich; and Whetstone, Somerset Road, Edgbaston, Birmingham.
1892. Kensington, Frederick, 2 Copthall Buildings, London, E.C.
1866. Kershaw, John, Marazion, St. Leonard's-on-Sea.
1884. Kershaw, Thomas Edward, Chilvers Coton Foundry, Nuneaton.
1890. Key, George Andrew, General Manager, Wallsend Pontoon Works, Bute Docks, Cardiff.

1885. Keyworth, Thomas Egerton, Ferro Carril Buenos Aires y Rosario, Campana, Buenos Aires, Argentine Republic: (or care of J. R. H. Keyworth, 28 Grosvenor Road, Birkenhead.)

1885. Kidd, Hector, Colonial Sugar Refining Co., Sydney, New South Wales.

1894. Kiernan, George, Manager, Messrs. Gresham and Craven, Craven Iron Works, Salford, Manchester.

1888. Kikuchi, Kyozo, Superintendent Engineer, Hirano Spinning Mill, Osaka, Japan.

1872. King, William, Engineer, Liverpool United Gas Works, Duke Street, Liverpool.

1893. Kinghorn, John Warden, care of Messrs. Jardine Matheson and Co., Hong Kong, China.

1889. Kirby, Frank Eugene, Constructing Engineer, Detroit Dry Dock Co., Detroit, Michigan, United States.

1877. Kirk, Henry, Messrs. Kirk Brothers and Co., New Yard Iron Works, Workington. [*Kirks, Workington.*]

1884. Kirkaldy, John, 40 West India Dock Road, London, E. [*Compactum, London.*]

1875. Kirkwood, James, Chief Inspector of Machinery for Pei Yang Squadron; care of Commissioner of Customs, Kowloon, Hong Kong, China: (or Melita Cottage, Denny.)

1864. Kirtley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W. [3005.]

1859. Kitson, Sir James, Bart., M.P., Monk Bridge Iron Works, Leeds.

1868. Kitson, John Hawthorn, Airedale Foundry, Leeds. [*Airedale, Leeds.*]

1874. Klein, Thorvald, 50 Southbrook Road, Lee, London, S.E.

1889. Knap, Conrad, 11 Queen Victoria Street, London, E.C.

1891. Knight, Bertrand Thornton, Post Office, Perth, Western Australia: (or care of Major Knight, Swansea.)

1886. Knight, Charles Albert, Babcock and Wilcox Boiler Co., 107 Hope Street, Glasgow.

1890. Knight, James Percy, Kaiser Steam Tug Co., 27 Great Tower Street, London, E.C. [*Longboat, London.* 11,203.]

1881. Laing, Arthur, Deptford Shipbuilding Yard, Sunderland.

1872. Laird, William, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead. [*Laird, Birkenhead.* 4003.]

1883. Lake, William Robert, 45 Southampton Buildings, London, W.C. [*Scopo, London.*]

1878. Lambourn, Thomas William, Naughton Hall, near Bildeston, S.O., Suffolk.

1881. Langdon, William, Locomotive Superintendent and Chief Mechanical Engineer, Rio Tinto Railway and Mines, Huelva, Spain: (or care of T. C. Langdon, Tamar Terrace, Launceston.)

1881. Lange, Frederick Montague Townshend, 53 bis Boulevard de la Liberté, Lille (Nord), France.

1893. Langford, William, Messrs. W. M. Ward and Co., Limerick Foundry, Great Bridge, Tipton.

1879. Langley, Alfred Andrew, 33 Chester Terrace, Regent's Park, London, N.W.

1879. Lapage, Richard Herbert, Elmwood, Surbiton, London, S.W.

1890. Last, Arthur John, Lieutenant R.A., Inspector of Ordnance Machinery, Mauritius.

1888. Latham, Baldwin, 13 Victoria Street, Westminster, S.W.; and Duppas House, Old Town, Croydon.

1890. Laurie, Leonard George, Mill Parade, Newport, Monmouthshire.

1867. Lawrence, Henry, The Grange Iron Works, Durham.

1893. Lawrie, James, Assistant Government Marine Surveyor, Singapore, Straits Settlements.

1874. Laws, William George, Borough Engineer and Town Surveyor, Town Hall, Newcastle-on-Tyne; and 5 Winchester Terrace, Newcastle-on-Tyne. [*Engineer, Newcastle-on-Tyne.*]

1882. Lawson, Frederick William, Messrs. Samuel Lawson and Sons, Hope Foundry, Leeds.

1870. Layborn, Daniel, Messrs. Daniel Layborn and Co., Dutton Street, Liverpool.

1883. Laycock, William S., Victoria Street Works, Sheffield; and Ranmoor, Sheffield. [*Invention, Sheffield.* 907.]

1860. Lea, Henry, Messrs. Henry Lea and Thornbery, 38 Bennett's Hill, Birmingham. [*Engineer, Birmingham.* 113.]

1892. Lea, Richard Henry, Manager, Messrs. Singer and Co.'s Cycle Works, Coventry.

1889. Leaf, Henry Meredith, Burlington Lodge, Streatham Common, London, S.W.

1883. Leavitt, Erasmus Darwin, Jun., 604 Main Street, Cambridgeport, Massachusetts, United States.

1890. Ledingham, John Machray, Royal Laboratory, Royal Arsenal, Woolwich.

1887. Lee, Cuthbert Ridley, Messrs. J. Coates and Co., Suffolk House, Laurence Pountney Hill, London, E.C.

1862. Lee, J. C. Frank, 108 Queen's Gate, London, S.W.

1892. Lee, Richard John, Messrs. Harrison Lee and Sons, City Foundry, Limerick.

1890. Lee, Samuel Edward, Messrs. Harrison Lee and Sons, City Foundry, Limerick.

1863. Lees, Samuel, Messrs. H. Lees and Sons, Park Bridge Iron Works, Ashton-under-Lyne.

1889. Legros, Lucien Alphonse, 57 Brook Green, Hammersmith, London, W.

1883. Lennox, John, 28 Victoria Street, Westminster, S.W.

1858. Leslie, Andrew, Coxlodge Hall, Newcastle-on-Tyne.

1883. Leslie, Joseph, 3 Canal Street, North Road, Entally, Calcutta, India.

1888. Letchford, Joseph, The Acacias, Greenhill Road, Harlesden, London, N.W.

1878. Lewis, Gilbert, 538 Eccles New Road, Eccles, Manchester.

1884. Lewis, Henry Watkin, Llwyn-yr-eos, Abercanaid, near Merthyr Tydfil.

1872. Lewis, Richard Amelius, Messrs. John Spencer and Sons, Tyne Hæmatite Iron Works, Scotswood-on-Tyne.

1884. Lewis, Sir William Thomas, Bute Mineral Estate Office, Aberdare; and Mardy, Aberdare.

1894. Liebert, Henry Anton, Messrs. John Holroyd and Co., Tomlinson Street, Hulme, Manchester.

1880. Lightfoot, Thomas Bell, Cornwall Buildings, 35 Queen Victoria Street, London, E.C. [*Separator, London.*]; and 7 Eastcombe Villas, Charlton Road, Blackheath, London, S.E.

1891. Lindsay, William Robertson, Messrs. W. B. Thompson and Co., Lilybank Engine Works, Dundee.

1890. Lineham, Wilfrid James, Professor of Engineering and Mechanical Science, The Goldsmiths' Institute, New Cross, London, S.E.; and Jesmond, Leyland Road, Lee, London, S.E.

1856. Linn, Alexander Grainger, 121 Upper Parliament Street, Liverpool.

1876. Lishman, Thomas, Mining Engineer, Hetton Colliery, near Fence Houses.

1881. List, John, Superintendent Engineer, Messrs. Donald Currie and Co., Orchard Works, Blackwall, London, E.; and 3 St. John's Park, Blackheath, London, S.E.

1885. Lister, Frank, Messrs. Lister and Co., Beechcliffe, Keighley; and Oaklands, Keighley.

1890. Lister, Robert Ramsbottom, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1866. Little, George, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham; and 23 Park Road, Southport.

1890. Livens, Frederick Howard, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln.

1886. Livsey, John Edward, Demonstrator in Mechanics and Mathematics, Royal College of Science, Exhibition Road, South Kensington, London, S.W.

1867. Lloyd, Charles, St. George's Club, Hanover Square, London, W.

1854. Lloyd, George Braithwaite (*Life Member*), Edgbaston Grove, Birmingham.

1882. Lloyd, Robert Samuel, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1894. Lloyd, Sampson Zachary, Managing Director, Engineering Department, Messrs. Nettlefolds, Birmingham [*Nettlefolds, Birmingham.*]; and Areley Hall, Stourport.

1890. Locke, Arthur Guy Neville, Alderney, Channel Isles.

1879. Lockhart, William Stronach, 5 Haddo Villas, Blackheath, London, S.E.

1884. Logan, Andrew Linton, Railway Signal Works, Worcester.

1890. Logan, John Walker, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester; and P.O. Box 2037, Johannesburg, Transvaal, South Africa.

1883. Logan, Robert Patrick Tredennick, Engineer's Office, Great Northern Railway of Ireland, Dundalk.

1874. Logan, William, Mining Engineer, Langley Park Colliery, Durham.

1884. Longbottom, Luke, Locomotive Carriage and Wagon Superintendent, North Staffordshire Railway, Stoke-on-Trent.

1894. Longridge, Captain Cecil Clement, Managing Director, Axle-box and Foundry Co., Central Works, Saltley, Birmingham. [*Beuthers, Birmingham.*]

1880. Longridge, Michael, Chief Engineer, Engine and Boiler Insurance Co., 12 King Street, Manchester.

1856. Longridge, Robert Bewick, Managing Director, Engine and Boiler Insurance Co., 12 King Street, Manchester; and Yew Tree House, Tabley, near Knutsford.

1875. Longridge, Robert Charles, Kilrie, Knutsford.

1880. Longworth, Daniel, care of Messrs. Finlay Muir and Co., Calcutta, India.

1887. Lorrain, James Grieve, Norfolk House, Norfolk Street, London, W.C. [*Lorrain, London.*]

1888. Low, David Allan, Head Master, The People's Palace Day Technical School, Mile End Road, London, E.

1861. Low, George, Bishop's Hill Cottage, Ipswich.

1885. Low, Robert, Powis Lodge, Vicarage Park, Plumstead.

1884. Lowcock, Arthur, Coleham Foundry, Shrewsbury.

1884. Lowdon, John, General Manager, Barry Graving Dock and Engineering Co., Exchange Buildings, Cardiff. [*Bardock, Cardiff.*]

1891. Lowdon, Thomas, Kingsland Crescent, Barry Docks, B.O., near Cardiff.

1873. Lowe, John Edgar, Messrs. Bolling and Lowe, 2 Laurence Pountney Hill, London, E.C. [*Bird, London.* 1530.]

1873. Lucas, Arthur, 27 Bruton Street, New Bond Street, London, W.

1889. Lucy, Arthur John, 9 Princess Square, Plymouth.

1886. Lucy, William Theodore, care of Frank Hudson, Central Uruguay Railway, Monte Video, Uruguay: (or Thornleigh, Woodstock Road, Oxford.)

1877. Lupton, Arnold, Professor of Mining Engineering, Yorkshire College, Leeds; and 6 De Grey Road, Leeds. [*Arnold Lupton, Leeds.* 330.]

1887. Lupton, Kenneth, Messrs. K. and H. Lupton, Well Street, Coventry. [*Luptons, Coventry.* 77.]

1878. Lynde, James Henry, Buckland, Ashton-on-Mersey, near Manchester.

1889. Macallan, George, Works Manager, Great Eastern Railway, Stratford Works, London, E.

1890. Macan, Richard Thompson, Dawlish House, Willesden, London, N.W.

1892. Macbean, John James, Messrs. Howarth Erskine and Co., Singapore, Straits Settlements.

1888. Macbeth, John Bruce King, 44 Tamarind Lane, Bombay, India: (or care of Norman Macbeth, Heaton, Bolton.)

1883. Macbeth, Norman, Messrs. John and Edward Wood, Victoria Foundry, Bolton.

1884. MacCarthy, Samuel, Messrs. Lloyd and Lloyd, 90 Cannon Street, London, E.C.; and 18 Adelaide Road, Brockley, London, S.E.

1877. MacColl, Hector, Strandtown, Belfast.

1889. Macdonald, James Alexander, Broad Oaks Iron Works, Chesterfield.

1892. Machado, Dr. Antonio Augusto, Manager, Companhia Metropolitana, Engineering and Boiler Works, Bahia, Brazil: (or care of Messrs. Heuser Humble and Co., 1 Fowkes Buildings, Great Tower Street, London, E.C.)

1892. Mackay, Charles O'Keefe, Locomotive Department, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1890. Mackay, Joseph, Bangkok Dock Co., Bangkok, Siam: (or care of Messrs. John Birch and Co., 10 Queen Street Place, London, E.C.) [*Mackay, Bangkok.*]

1885. Mackenzie, John William, Messrs. Wheatley and Mackenzie, 40 Chancery Lane, London, W.C.; and Northfield, Oxford Road, Upper Teddington, S.O., Middlesex.

1894. Mackie, John, 165 King's Road, Reading.

1875. Maclagan, Robert, Blantyre, British Central Africa: (or care of Dr. Maclagan, 9 Cadogan Place, Belgrave Square, London, S.W.)

1889. MacLay, Alexander, Professor of Mechanical Engineering, Glasgow and West of Scotland Technical College, 38 Bath Street, Glasgow.

1886. MacLean, Alexander Scott, Messrs. Alexander Scott and Sons, Sugar Refinery, Berry-yards, Greenock; and 31 Bank Street, Greenock.

1877. MacLellan, John A., Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow. [*Alley, Glasgow.* 673.]

1888. Macleod, Arthur William, Schwebo Mining Syndicate, Kyouk Myoung Post Office, Upper Burmah.

1864. Macnab, Archibald Francis, Tokyo, Japan.

1884. Macpherson, Alexander Sinclair, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1892. Mactear, James, F.R.S.E., 28 Victoria Street, Westminster, S.W. [*Celestine, London.* 3066.]

1879. Maginnis, James Porter, 9 Carteret Street, Queen Anne's Gate, Westminster, S.W. [*James Maginnis, London;* and *Offsett, London.*]

1891. Mahon, Reginald Henry, Captain R.A., Superintendent, H. M. Shell Factory, Cossipore, Calcutta, India.

1873. Mair-Rumley, John George (*Life Member*), Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W. [*Aquosity, London.*]

1884. Mais, Henry Coathupe, 2 Prell's Buildings, Collins and Queen Streets, Melbourne, Victoria.

1883. Malan, Ernest de Mérindol, Signal and Telegraph Department, Hull Barnsley and West Riding Junction Railway and Dock Co., Alexandra Dock, Hull. [*Engineer, Deepdock, Hull. Nat.* 106.]

1879. Malcolm, Bowman, Locomotive Superintendent, Belfast and Northern Counties Railway, Belfast.

1891. Manisty, Edward, Dundalk Iron Works, Dundalk, Ireland; and 24A Bryanston Square, London, W.

1894. Mann, James Hutchinson, Messrs. Mann and Charlesworth, Canning Works, Dewsbury Road, Leeds. [*Canning, Leeds.* 1335.]

1888. Mano, Bunji, Professor of Mechanical Engineering, Imperial University, Tokyo, Japan.

1875. Mansergh, James, 5 Victoria Street, Westminster, S.W.

1894. Mansfield, Edwin, Messrs. Edwin Mansfield and Sons, 140 Great Clowes Street, Broughton, Manchester. [*Gaslight, Manchester.*]

1891. Manson, James, Locomotive Superintendent, Glasgow and South Western Railway, Kilmarnock.

1862. Mappin, Sir Frederick Thorpe, Bart., M.P., Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield; and Thornbury, Sheffield.

1878. Marié, Georges, Ingénieur Chef de Division, Chemins de fer de Paris à Lyon et à la Méditerranée, 7 Rue du Clos d'Orléans, Fontenay-sous-Bois, Seine, France.

1891. Marks, Edward Charles Robert, 13 Temple Street, Birmingham.

1888. Marks, George Croydon, 13 Temple Street, Birmingham. [*Pumps, Birmingham.*]

1884. Marquand, Augustus John, 2 Dock Chambers, Bute Docks, Cardiff. [*Martial, Cardiff.*]

1887. Marriott, William, Engineer and Locomotive Superintendent, Midland and Great Northern Joint Railways, Melton Constable, Norfolk.

1887. Marsden, Benjamin, Messrs. S. Marsden and Son, Screw-Bolt and Nut Works, London Road, Manchester.

1871. Marsh, Henry William, Winterbourne, near Bristol.

1875. Marshall, Rev. Alfred (*Life Member*), The Vicarage, Feckenham, Redditch.

1865. Marshall, Francis Carr, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1890. Marshall, Frank Herbert, Ormesby Iron Works, Middlesbrough.

1885. Marshall, Henry Dickenson, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 6648.]

1871. Marshall, James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 6648.]

1885. Marshall, Jenner Guest, Messrs. Chance Brothers and Co., Glass Works, near Birmingham; and Westcott Barton Manor, Oxfordshire.

1877. Marshall, William Bayley, Richmond Hill, Edgbaston, Birmingham. [*Augustus, Birmingham.*]

1847. Marshall, William Prime, Richmond Hill, Edgbaston, Birmingham. [*Augustus, Birmingham.*]

1859. Marten, Edward Bindon, Pedmore, Stourbridge. [*Marten, Stourbridge.* 8504.]

1881. Martin, Edward Pritchard, Dowlais Iron Works, Dowlais.

1888. Martin, Henry James, Tresleigh House, Walters Road, Swansea.

1889. Martin, The Hon. James, Messrs. James Martin and Co., Phœnix Foundry, Gawler, South Australia: (or care of J. C. Lanyon, 27 Gresham House, Old Broad Street, London, E.C.)

1892. Martin, Thomas George, Messrs. James McGowan and Co., Wapping Wall, London, E.

1886. Martin, William Hamilton, Engineering Manager, The Scheldt Royal Shipbuilding and Engineering Works, Flushing, Holland.

1882. Martindale, Warine Ben Hay, 38 Parliament Street, Westminster, S.W.; and Overfield, Bickley, R.S.O., Kent.

1882. Masefield, Robert, 14 Markham Square, Chelsea, London, S.W.

1884. Massey, George, Post Office Chambers, Pitt Street, Sydney, New South Wales.

1890. Massey, Stephen, Messrs. B. and S. Massey, Openshaw, Manchester.

1893. Massey, William Henry, 25 Queen Anne's Gate, Westminster, S.W.; and Twyford, R.S.O., Berkshire.

1892. Masterton, John Fraser, Locomotive Department, South Eastern Railway, Ashford, Kent.

1894. Mather, George Radford, Messrs. G. R. Mather and Son, Albion Foundry, Wellingborough. [*Mather, Wellingborough.*]

1867. Mather, William, M.P., Messrs. Mather and Platt, Salford Iron Works, Manchester. [*Mather, Manchester.*]

1883. Mather, William Penn, Queen Dyeing Co., Providence, Rhode Island, United States.

1882. Matheson, Henry Cripps, Enfield, Sunny Gardens, Hendon, London, N.W.

1891. Mathewson, Jeremiah Eugene, Tilghman's Sand-Blast Co., Bellefield Works, Bellefield Lane, Sheffield.

1886. Matthews, Robert, Parrs House, Heaton Mersey, near Manchester.

1875. Mattos, Antonio Gomes de, Messrs. Maylor and Co., Engineering Works, 136 Rua da Sande, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1853. Maudslay, Henry (*Life Member*), Westminster Palace Hotel, 4 Victoria Street, Westminster, S.W.: (or care of John Barnard, 47 Lincoln's Inn Fields, London, W.C.)

1893. Maunsell, Richard Edward Lloyd, Locomotive Department, East Indian Railway, Jamalpur, Bengal, India: (or care of John Maunsell, Edenmore, Raheny, Co. Dublin.)

1873. Maw, William Henry, 35 Bedford Street, Strand, London, W.C. [3663.]

1884. Maxim, Hiram Stevens, Maxim Nordenfelt Guns and Ammunition Co., 32 Victoria Street, Westminster, S.W.

1859. Maylor, William, Chesterleigh, Albemarle Road, Beckenham.

1874. McClean, Frank, Norfolk House, Norfolk Street, Strand, London, W.C.

1891. McCredie, Arthur Latimer, 250 Pitt Street, Sydney, New South Wales. [*Ebony, Sydney.* 63.]

1892. McDonald, John, Locomotive Works, Imperial Government Railways, Tokyo, Japan.

1878. McDonald, John Alexander, Assistant Engineer for Roads and Bridges, Public Works Office, Sydney, New South Wales: (or care of James E. McDonald, 4 Chapel Street, Cripplegate, London, E.C.)

1865. McDonnell, Alexander, 28 Victoria Street, Westminster, S.W.; and The Cedars, Norwood Green, Southall.

1891. McFarlane, George, Sun Insurance Buildings, 121 West George Street, Glasgow. [*Dunsloy, Glasgow.* 3777.]

881. McGregor, Josiah, Crown Buildings, 78 Queen Victoria Street, London, E.C. [*Sahib, London.*]

1892. McGregor, Peter (*Life Member*), Imperial Maritime Customs, Kowloon, Hong Kong, China.

1892. McIntosh, William Forbes, Messrs. Douglas Lapraik and Co., Hong Kong, China.

1889. McIntyre, John Henry A., Lecturer on Mechanical Engineering, Allan Glen's School, Glasgow.

1881. McKay, John, 13 Grey Street, Newcastle-on-Tyne; and 18 Northumberland ourt, Newcastle-on-Tyne.

1880. McLachlan, John, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]

1888. McLaren, Henry, Messrs. J. and H. McLaren, Midland Engine Works, Leeds.

1882. McLaren, Raynes Lauder, 22 George Street, Hanover Square, London, W.

1888. McLarty, Farquhar Matheson, Penang Foundry, Penang: (or care of William Bow, Thistle Engine Works, Paisley.) [*McLarty, Penang.*]

1885. McNeil, John, Messrs. Aitken McNeil and Co., Helen Street, Govan, Glasgow. [*Colonial, Glasgow.*]

1894. McQueen, John, Messrs. John Hetherington and Sons, Vulcan Works, Pollard Street, Manchester.

1891. Meade, Thomas de Courcy, Town Hall, Manchester; and Kenmore, Didsbury, Manchester.

1882. Meats, John Tempest, Mason Machine Works, Taunton, Massachusetts, United States.

1881. Meik, Charles Scott, care of P. Walter Meik, 16 Victoria Street, Westminster, S.W.

1858. Meik, Thomas, 13 Newbattle Terrace, Edinburgh.

1887. Melhuish, Frederick, Assistant Engineer, Southwark and Vauxhall Water Works, Southwark Bridge Road, London, S.E.

1891. Melville, William Charles, Superintendent Engineer, Liverpool Steam Tug Co., 44 Chapel Street, Liverpool.

1888. Melville, William Wilkie, 151 Burngreave Road, Sheffield.

1878. Menier, Henri, 56 Rue de Châteaudun, Paris.

1876. Menzies, William, Messrs. Menzies and Co., 50 Side, Newcastle-on-Tyne. [*William Menzies, Newcastle-on-Tyne. G.P.O.* 200. *Nor. Dis.* 1144.]

1894. Merrick, Robert, Warren's Place Iron Works, Cork.

1875. Merryweather, James Compton, Messrs. Merryweather and Sons, Fire-Engine Works, Greenwich Road, London, S.E.; and 63 Long Acre, London, W.C. [*Merryweather, London.*]

1891. Metcalfe, Frederick Spencer, Pumping Station, Sewage Works, Burton-on-Trent.

1881. Meysey-Thompson, Arthur Herbert, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds.

1877. Michele, Vitale Domenico de, 14 Delahay Street, Westminster, S.W.; and Higham Hall, Rochester.

1884. Middleton, Reginald Empson, 17 Victoria Street, Westminster, S.W.

1891. Middleton, Robert, Sheepscar Foundry, Leeds.

1891. Middleton, Robert Thomas, Superintendent of Bridge Works, Bombay Baroda and Central India Railway, Bombay, India.

1886. Midelton, Thomas, Aylesbury, Albemarle Street, North Kingston, Sydney, New South Wales.

1862. Miers, Francis C., Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.; and Eden Cottage, West Wickham Road, Beckenham. [*Foundation, London.* 1920.]

1874. Milburn, John, Hawkshead Foundry, Quay Side, Workington.

1887. Miles, Frederick Blumenthal, Messrs. Bement Miles and Co., Callowhill and Twenty-first Streets, Philadelphia, United States.

1893. Millar, Jackson, Messrs. Riley Hargreaves and Co., 11 Merchant Road, Singapore, Straits Settlements: (or care of J. R. Allan, 93 Hope Street, Glasgow.)

1889. Miller, Adam, 50 Lime Street, London, E.C.

1885. Miller, Harry William, New Chimes Gold Mining Co., P.O. Box 1083, Johannesburg, Transvaal, South Africa.

1886. Miller, John Smith, Messrs. Smith Brothers and Co., Hyson Green Works, Nottingham.

1887. Miller, Thomas Lodwick, 7 Tower Buildings N., Water Street, Liverpool.

1893. Milligan, William Scott, Messrs. Pollit and Wigzell, Bank Foundry, Sowerby Bridge.

1893. Millington, Frederick Handel, Manager, Patent Pulp Manufacturing Co., Thetford; and Mill House, Thetford.

1885. Millis, Charles Thomas, Principal, Educational Department, Borough Road Polytechnic, London, S.E.

1887. Milne, William, Castle Buildings, West Street, Durban, Natal [*Metallic, Durban*]; and The Oaks, 52 Queen Street, Durban, Natal.

1856. Mitchell, Charles, Sir W. G. Armstrong Mitchell and Co., Low Walker, Newcastle-on-Tyne; and Jesmond Towers, Newcastle-on-Tyne.

1892. Mitcheson, George Arthur, Longton, Staffordshire. [*Mitcheson, Longton.* 445.]

1870. Moberly, Charles Henry, 13 Belmont Park, Lee, London, S.E.

1885. Moir, James, Superintendent Engineer, Bombay Steam Navigation Co., Frere Road, Bombay.

1879. Molesworth, Sir Guilford Lindsay, K.C.I.E., The Manor House, Bexley, S.O., Kent.

1882. Molesworth, James Murray, Aberdeen House, Upper Holly Walk, Leamington.

1881. Molinos, Léon, 48 Rue de Provence, Paris.

1884. Monroe, Robert, Manager, Penarth Slipway and Engineering Works, Penarth Dock, Penarth.

1884. Moore, Benjamin Theophilus, Longwood, Bexley, S.O., Kent.

1876. Moore, Joseph, 1099 Adeline Street, Oakland, San Francisco, California; Fairhope, Byne Road, Sydenham, London, S.E.: (or care of Ralph Moore, Government Inspector of Mines, 13 Clairmont Gardens, Glasgow.)

1880. Moreland, Richard, Messrs. Richard Moreland and Son, 3 Old Street, St. Luke's, London, E.C. [*Expansion, London.*]

1889. Morgan, David John, 16 Barry Dock Road, Barry, near Cardiff.

1885. Morgan, Thomas Rees, Morgan Engineering Works, Alliance, Ohio, United States.

1887. Morison, Donald Barns, Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1888. Morris, Charles, Messrs. Jessop and Co., Phœnix Iron Works, Calcutta, India.

1874. Morris, Edmund Legh, New River Water Works, Finsbury Park, London, N.

1890. Morris, Francis Sanders, 4 Trafalgar Square, London, W.C.

1890. Morris, John Alfred (*Life Member*), Empire Works, 78 Great Bridgewater Street, Manchester.

1892. Morton, David Home, 95 Bath Street, Glasgow.

1858. Mountain, Charles George, 93 Hope Street, Glasgow.

1886. Mountain, William Charles, Messrs. Ernest Scott and Mountain, Close Works, Newcastle-on-Tyne [*Esco, Newcastle-on-Tyne.* 432.]; and 9 St. George's Terrace, Jesmond, Newcastle-on-Tyne.

1884. Mower, George A., Crosby Steam Gage and Valve Co., 75 Queen Victoria Street, London, E.C. [*Crosby, London.*]

1885. Mudd, Thomas, Manager, Central Marine Engine Works, West Hartlepool.

1873. Muir, Alfred, Messrs. William Muir and Co., Britannia Works, Sherbourne Street, Strangeways, Manchester.

1873. Muir, Edwin, 37 Brown Street, Manchester.

1876. Muirhead, Richard, Kentish Engineering Works, Maidstone. [*Muirhead, Maidstone.*]

1890. Müller, Henry Adolphus, Locomotive Superintendent, Municipal Railway, 3 North Road, Entally, Calcutta, India.

1890. Mumford, Charles Edward, St. Andrew's Works, Bury St. Edmunds.

1890. Munro, John, Professor of Mechanical Engineering, Merchant Venturers' Technical College, Unity Street, Bristol.

1890. Munro, Robert Douglas, Chief Engineer, Scottish Boiler Insurance and Engine Inspection Co., 13 Dundas Street, Glasgow.

1889. Münster, Bernard Adolph, Engineer, Yokohama, Japan.

1891. Murdoch, Robert Macmillan, Phœnix Metal Die and Engineering Co., 110 Stamford Street, Blackfriars, London, S.E.

1890. Murray, Alexander John, Chief Mechanical Engineer, Government Gun-Powder Factory, Kirkee, Bombay, India.

1890. Murray, Kenneth Sutherland, Brin's Oxygen Works, 69 Horseferry Road, Westminster, S.W.

1891. Murray, Thomas Roberts, Messrs. L. Sterne and Co., Crown Iron Works, Glasgow.

1881. Musgrave, James, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1882. Musgrave, Walter Martin, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1888. Myers, William Beswick (*Life Member*), 14 Victoria Street, Westminster, S.W.

1870. Napier, James Murdoch, Messrs. David Napier and Son, Vine Street, York Road, Lambeth, London, S.E.

1889. Nash, Thomas, Sheffield Testing Works, Blonk Street, Sheffield; and Guzerat House, Nether Edge, Sheffield.

1888. Nathan, Adolphus, Messrs. Larini Nathan and Co., Milan; and 15 Via Bigli, Milan, Italy.

1861. Naylor, John William, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1883. Neate, Percy John, 16 The Banks, High Street, Rochester.

1889. Needham, Joseph Edward, Patent Office, 25 Southampton Buildings, London, W.C.

1892. Nelson, Arthur David, Hay and Lackey Streets, Sydney, New South Wales. [*Nelson, Sydney.* 160.]

1884. Nelson, John, Contractors' Office, Dringhouses, York.

1887. Nelson, Sidney Herbert, Messrs. Samuel Worssam and Co., Oakley Works, King's Road, Chelsea, London, S.W.

1881. Nesfield, Arthur, 14 Water Street, Liverpool.

1890. Newton, Percy, Vassall Lodge, Addison Road, Kensington, London, W.

1884. Nicholls, James Mayne, Locomotive Superintendent, Nitrate Railways, Iquique, Chili.

1884. Nicholson, Henry, care of G. H. Hill, Albert Chambers, Albert Square, Manchester.

1894. Nicholson, John Rumney, care of Messrs. Blackburn and Main, Solicitors, Carlisle.

1891. Nicholson, Thomas, Crownpoint Boiler Works, St. Marnock Street, Crownpoint Road, Glasgow.

1886. Noakes, Thomas Joseph, Messrs. Thomas Noakes and Sons, 35 and 37 Brick Lane, Whitechapel, London, E.

1884. Noakes, Walter Maplesden, 73 Clarence Street, Wynyard Square, Sydney, New South Wales.

1882. Nordenfelt, Thorsten, 8 Rue Auber, Paris.

1892. Norris, William, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1868. Norris, William Gregory, Coalbrookdale Iron Works, Coalbrookdale, Shropshire.

1883. North, Gamble, Pisagua, Chile: (or care of B. Depledge, Woolpack Buildings, 3 Gracechurch Street, London, E.C.)

1882. North, John Thomas, Messrs. North Humphrey and Dickenson, Engineering Works, Iquique, Chile; Woolpack Buildings, 3 Gracechurch Street, London, E.C.; and Avery House, Avery Hill, Eltham.

1878. Northcott, William Henry, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E.; and 7 St. Mary's Road, Peckham, London, S.E. [*Oxygen, London.* 8007.]

1888. Norton, William Eardley, 8 Great George Street, Westminster, S.W.

1882. Nunneley, Thomas, Barwick-in-Elmet, near Leeds.

1885. Oakes, Sir Reginald Louis, Bart., Société Anonyme La Métallurgique, 1 Place de Louvain, Bruxelles, Belgium.

1887. O'Brien, Benjamin Thompson, 60 Upper Parliament Street, Liverpool.

1887. O'Brien, John Owden, Messrs. W. P. Thompson and Co., Ducie Buildings, 6 Bank Street, Manchester.

1890. Ockendon, William, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.

1868. O'Connor, Charles, 144 Osborne Villas, Duke Street, Southport.

1888. O'Donnell, John Patrick, 70 and 71 Palace Chambers, 9 Bridge Street, Westminster, S.W.; and Avondale, College Road, Bromley, Kent. [*ODonnell, London.* 3059.]

1889. Ogden, Fred, Patent Office, 25 Southampton Buildings, London, W.C.

1886. Ogle, Percy John, 4 Bishopsgate Street Within, London, E.C. [*Oglio, London.* 2463.]

1894. Oka, Saneyasu, 141, 1 Chome, Funakori Cho, Osaka, Japan.

1893. Oke, Francis Robert, London and North Western Railway Works, Crewe.

1875. Okes, John Charles Raymond, 39 Queen Victoria Street, London, E.C. [*Oaktree, London.*]

1882. Orange, James, Messrs. Danby Leigh and Orange, Hong Kong, China: (or care of Mrs. Mary Orange, 2 West End Terrace, Jersey.)

1885. Ormerod, Richard Oliver, 35 Philbeach Gardens, South Kensington, London, S.W.

1867. Oughterson, George Blake, care of Peter Brotherhood, Belvedere Road, Lambeth, London, S.E.

1889. Owen, Thomas, Midland Railway, Derby.

1868. Paget, Arthur, Loughborough. [*Paget Company, Loughborough.*]

1877. Panton, William Henry, Messrs. Dorman Long and Co., Middlesbrough.

1877. Park, John Carter, 68 Priory Road, West Hampstead, London, N.W.

1872. Parker, Thomas, Gorton House, Gorton, near Manchester.

1888. Parker, Thomas, Jun., Carriage and Wagon Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester; and Gorton House, Gorton, near Manchester.

1891. Parker, Thomas, F.R.S.E., Manor House, Tettenhall, Wolverhampton. [*Parker, Tettenhall.*]

1871. Parkes, Persehouse, Messrs. Persehouse Parkes and Co., 21 Drury Buildings, 21 Water Street, Liverpool. [*Fibrous, Liverpool.*]

1884. Parlane, William, Manager, Hong Kong Ice Company, Hong Kong, China: (or Ladyton Cottage, Bonhill, Dumbartonshire.)

1892. Parratt, William Heather, Enmore Plantation, East Coast, Demerara, British Guiana.

1892. Parrott, Thomas Henry, Messrs. G. E. Belliss and Co., Ledsam Street, Birmingham.

1886. Parry, Alfred, Messrs. Parry and Co., Vulcan Iron Works, Calcutta, India: (or care of Messrs. J. B. Barry and Son, 110 Cannon Street, London, E.C.)

1889. Parry, Evan Henry, Eagle Chambers, Adelaide Street, Swansea.

1878. Parsons, The Hon. Richard Clere, Messrs. Bateman Parsons and Bateman, 39 Victoria Street, Westminster, S.W. [*Outfall, London.* 3233]; and 48 Prince's Gardens, London, S.W.

1886. Passmore, Frank Bailey, Mansion House Chambers, 11 Queen Victoria Street, London, E.C. [*Knarf, London.*]

1880. Paterson, Walter Saunders, Bombay Burmah Trading Corporation, Rangoon, British Burmah, India: (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1877. Paton, John McClure Caldwell, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham. [*Manloves, Nottingham.*]

1891. Paton, Robert J., Companhia McHardy, Campinas, São Paulo, Brazil.

1881. Patterson, Anthony, Dowlais Iron Works, Dowlais.

1883. Pattison, Giovanni, Messrs. C. and T. T. Pattison, Engineering Works, Naples. [*Pattison, Naples.*]

1891. Pattison, Joseph, 123 Bute Street, Cardiff.

1891. Paul, Matthew, Jun., Messrs. Matthew Paul and Co., Levenford Works, Dumbarton.

1891. Paulson, Scott, Box 455, Johannesburg, Transvaal, South Africa: (or care of Dr. Paulson, Mount Sorrel, near Loughborough.)

1872. Paxman, James Noah, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester. [*Paxman, Colchester.*]

1880. Peache, James Courthope, 87 East Hill, Colchester.

1890. Peacock, Francis, Locomotive Superintendent, Smyrna and Cassaba Railway, Smyrna, Turkey in Asia.

1890. Peacock, James Albert Wells, Assistant Locomotive Superintendent, Smyrna and Cassaba Railway, Smyrna, Turkey in Asia.

1869. Peacock, Ralph, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1879. Pearce, George Cope, Ryefields, Ross.

1873. Pearce, Richard, Carriage and Wagon Superintendent, East Indian Railway, Howrah, Bengal, India.

1894. Pearce, Robert McLardy, care of National Bank of India, 47 Threadneedle Street, London, E.C.

1884. Pearson, Frank Henry, Earle's Shipbuilding and Engineering Works, Hull.

1885. Pearson, Henry William, Engineer, Bristol Water Works, Small Street, Bristol.

1870. Pearson, Thomas Henry, Moss Side Iron Works, Ince, near Wigan.

1888. Peel, Charles Edmund, Quay Parade, Swansea.

1884. Penn, George Williams, Lloyd's Bute Proving House, Cardiff.

1873. Penn, John, M.P., Messrs. John Penn and Sons, Marine Engineers, Greenwich, London, S.E.

1873. Penn, William, Messrs. John Penn and Sons, Marine Engineers, Greenwich, London, S.E.

1874. Pepper, Joseph Ellershaw, Clarence Iron Works, Leeds.

1874. Percy, Cornelius McLeod, King Street, Wigan.

1879. Perkins, Stanhope, Healey Terrace, Fairfield, near Manchester.

1890. Perry, Weston Alcock, Phosphor-Bronze Co., Birmingham; and Kenwood, St. Peter's Road, Birmingham.

1893. Philip, William Littlejohn, Manager, Messrs. Spencer and Co., Melksham Foundry, Melksham.

1881. Philipson, John, Messrs. Atkinson and Philipson, Carriage Manufactory, 27 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]

1885. Phillips, Charles David, Emlyn Engineering Works, Newport, Monmouthshire. [*Machinery, Newport, Mon.*]

1878. Phillips, John, 4 Corona Road, Burnt Ash Hill, Lee, London, S.E.

1885. Phillips, Lionel, Mining Engineer, Bultfontein Diamond Mine, Kimberley, South Africa; and care of H. Eckstein, Box 149, Johannesburg, Transvaal, South Africa.

1879. Phillips, Robert Edward, Royal Courts Chambers, 70 and 72 Chancery Lane, London, W.C.; and 47 Sussex Place, Onslow Gardens, London, S.W. [*Phicycle, London.*]

1890. Phillips, Walter, 28 Brownhill Road, Catford, London, S.E.

1882. Phipps, Christopher Edward, Locomotive Superintendent, Madras Railway, Perambore Works, Madras, India.

1894. Pickering, Jonathan, Resident Engineer, Colonial Sugar Refining Co., Sydney, New South Wales; and Broadwater, Richmond River, New South Wales: (or care of R. Y. Pickering, Wishaw, near Glasgow.)

1876. Piercy, Henry James Taylor, Messrs. Piercy and Co., Broad Street Engine Works, Birmingham. [*Piercy, Birmingham.* 20.]

1877. Pigot, Thomas Francis, 41 Upper Mount Street, Dublin.

1888. Pilkington, Herbert, Wellingborough Iron Works, Wellingborough.

1883. Pillow, Edward, 2 Carlton Terrace, Mill Mill Road, Norwich.

1892. Pinder, Charles Ralph, New Rietfontein Estate and Gold Mines, P. O. Box 661, Johannesburg, Transvaal, South Africa.

1876. Pinel, Charles Louis, Messrs. Lethuillier and Pinel, 26 Rue Meridienne, Rouen, France. [*Lethuillier Pinel, Rouen.*]

1892. Pirie, George, 137 Maxey Road, Plumstead.

1882. Pirrie, John Sinclair, Austral Otis Elevator and Engineering Works, South Melbourne, Victoria: (or care of Messrs. John Birch and Co., 11 Queen Street Place, London, E.C.)

1888. Pirrie, William James, Messrs. Harland and Wolff, Belfast.

1883. Pitt, Walter, Messrs. Stothert and Pitt, Newark Foundry, Bath. [*Stothert, Bath.*]

1887. Place, John, Linotype Co., 6 Serjeants' Inn, Fleet Street, London, E.C.

1871. Platt, James, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester [*Atlas, Gloucester.*]; and Somerset House, Gloucester. [*Platt, Gloucester.*]

1883. Platt, James Edward, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. Platt, Samuel Radcliffe (*Life Member*), Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1878. Platts, John Joseph, Resident Engineer, Odessa Water Works, Odessa, Russia.

1869. Player, John, Clydach Foundry, near Swansea.

1892. Pogson, Alfred Lee, Engineer-in-Chief, Harbour Trust Board and Works, Madras, India.

1888. Pogson, Joseph, Manager and Engineer, Huddersfield Corporation Tramways, Huddersfield.

1894. Poland, William, Messrs. William Poland and Co., 24 Green Street, Blackfriars, London, S.E. [*Determine, London.*]

1893. Pollit, Edward Ernest, Messrs. Pollit and Wigzell, Bank Foundry, Sowerby Bridge.

1894. Pollitt, Harry, Chief Locomotive Engineer, Manchester Sheffield and Lincolnshire Railway, Gorton, Manchester. [*Traction, Gorton.*]

1886. Pollock, James, 22 Billiter Street, London, E.C. [*Specific, London.*]

1876. Pooley, Henry, Messrs. Henry Pooley and Son, Albion Foundry, Liverpool. [*Pooley, Liverpool.*]

1890. Potter, William Henry, Newcastle Chambers, Angel Row, Nottingham.

1864. Potts, Benjamin Langford Foster, 55 Chancery Lane, London, W.C.; and 117 Camberwell Grove, London, S.E.

1878. Powel, Henry Coke, Tintern House, 64 Burnt Ash Hill, Lee, London, S.E.

1890. Powell, James Richard, Pierhead Chambers, Cardiff.

1874. Powell, Thomas, Brynteg, Neath.

1891. Powles, Henry Handley Pridham, Faraday House, Charing Cross Road, London, W.C.

1867. Pratchitt, John, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1865. Pratchitt, William, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1892. Pratt, Middleton, 6 Richmond Terrace, New Brighton, near Birkenhead.

1885. Pratten, William John, Messrs. Harland and Wolff, Belfast.

1890. Preece, William Henry, C.B., F.R.S., General Post Office, St. Martin's-le-Grand, London, E.C.

1882. Presser, Ernest Charles Antoine, 4 Salesas, Madrid.

1877. Price, Henry Sherley, Messrs. Wheatley Kirk, Price, and Goulty, 49 Queen Victoria Street, London, E.C. [*Indices, London.*]

1866. Price, John, 6 Osborne Villas, Jesmond, Newcastle-on-Tyne.

1890. Price, John, Inspecting Engineer, Workington.

1889. Price, John Bennett, Messrs. Charles Macintosh and Co., Cambridge Street, Manchester; and Wyresdale, Wilbraham Road, Chorlton-cum-Hardy, near Manchester.

1859. Price-Williams, Richard, 32 Victoria Street, Westminster, S.W. [*Spandrel, London.*]

1886. Price-Williams, Seymour William, 5 Victoria Street, Westminster, S.W.

1874. Prosser, William Henry, Messrs. Harfield and Co., Mansion House Buildings, 4 Queen Victoria Street, London, E.C.

1894. Pryce, Henry James, Locomotive Superintendent, North London Railway, Bow Road Works, London, E.

1890. Pugh, Charles Henry, Whitworth Works, Rea Street South, Birmingham.

1887. Pullen, William Wade Fitzherbert, Walmer House, 5 Romilly Road, Cardiff.

1884. Puplett, Samuel, 47 Victoria Street, Westminster, S.W.

1866. Putnam, William, Darlington Forge, Darlington.

1887. Pyne, Sir Thomas Salter, C.S.I., care of H.H. the Ameer of Afghanistan, Kabul: (or care of E. C. Clarke, Foreign Office, Government of India, Simla or Calcutta, India: or care of Edmund Neel, C.I.E., India Office, Whitehall, London, S.W.)

1892. Quentrall, Thomas, H.M. Inspector of Mines, Kimberley, South Africa.

1893. Quirk, Edward, Chief Mechanical Engineer, Trinity House, London, E.C.

1870. Radcliffe, William (*Life Member*), Camden House, 25 Collegiate Crescent, Sheffield.

1878. Radford, Richard Heber, 15 St. James' Row, Sheffield. [*Radford, Sheffield.*]

1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1884. Rafarel, William Claude, Barnstaple Foundry and Engineering Works, Victoria Road, Barnstaple. [*Rafarel, Barnstaple.*]

1885. Rainforth, William, Britannia Iron Works, Lincoln. [*Rainforths, Lincoln.*]

1878. Rait, Henry Milnes, Messrs. Rait and Gardiner, 155 Fenchurch Street, London, E.C. [*Repairs, London.*]

1892. Ramsay, William, Superintendent Engineer, Scottish Oriental Steamship Co., Hong Kong, China.

1847. Ramsbottom, John, Fernhill, Alderley Edge, Cheshire.

1866. Ramsden, Sir James, Abbot's Wood, Barrow-in-Furness; and Reform Chambers, 105 Pall Mall, London, S.W.

1860. Ransome, Allen, 304 King's Road, Chelsea, London, S.W. [*Ransome, London.*]

1886. Ransome, James Edward, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich. [*Ransomes, Ipswich.*]

1873. Rapier, Richard Christopher, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich; and 32 Victoria Street, Westminster, S.W. [*Ransomes Rapier, Westminster.*]

1888. Rapley, Frederick Harvey, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C.

1889. Ratcliffe, James Thomas, Baumwoll-Manufactur von Izr. K. Poznanski, Lodz, Russian Poland.

1883. Rathbone, Edgar Philip, Standard Bank Buildings, and P. O. Box 963, Johannesburg, Transvaal, South Africa. [*Viking, Johannesburg.*]

1867. Ratliffe, George, 7A Laurence Pountney Hill, London, E.C.

1893. Raven, Vincent Litchfield, Locomotive Department, North Eastern Railway, Darlington.

1862. Ravenhill, John Richard, Delaford, Iver, near Uxbridge.

1872. Rawlins, John, Manager, Metropolitan Railway-Carriage and Wagon Works, Saltley, Birmingham. [*Metro, Birmingham.*]

1883. Reader, Reuben, Phœnix Works, Cremorne Street, Nottingham.

1887. Readhead, Robert, Messrs. John Readhead and Sons, West Docks, South Shields. [*Readhead, South Shields.* G.P.O. 14. Nat. 2024.]

1882. Reay, Thomas Purvis, Messrs. Kitson and Co., Airedale Foundry, Leeds.

1881. Redpath, Francis Robert, Canada Sugar Refinery, Montreal, Canada. [*Redpath, Montreal.*]

1883. Reed, Alexander Henry, 64 Mark Lane, London, E.C. [*Wagon, London.*]

1870. Reed, Sir Edward James, K.C.B., M.P., F.R.S., Broadway Chambers, Westminster, S.W. [*Carnage, London.*]

1894. Reed, Joseph William, Manager, Engine Works Department, Palmer's Shipbuilding and Iron Works, Jarrow.

1891. Reed, Thomas Alfred, Bute Docks, Cardiff. [*Steam, Cardiff.* 171.]

1884. Rees, William Thomas, Mining Engineer, Maesyffynon, Aberdare.

1891. Reid, Hugh (*Life Member*), Messrs. Neilson and Co., Hyde Park Locomotive Works, Glasgow.

1883. Reid, James, Messrs. Neilson and Co., Hyde Park Locomotive Works, Glasgow.

1889. Rendell, Alan Wood, Locomotive Superintendent, East Indian Railway, Jamalpur, Bengal, India: (or 21A Goldhurst Terrace, South Hampstead, London, N.W.)

1890. Rendell, Samuel, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and New Mills, near Stockport.

1859. Rennie, George Banks, 20 Lowndes Street, Lowndes Square, London, S.W.

1879. Rennie, John Keith, 49 Queen's Gate, London, S.W.

1881. Rennoldson, Joseph Middleton, Marine Engine Works, South Shields. [*Rennoldson, South Shields.* 11.]

1876. Restler, James William, Engineer, Southwark and Vauxhall Water Works, Southwark Bridge Road, London, S.E.

1883. Reunert, Theodore (*Life Member*), Box 209, Kimberley, South Africa; Box 92, Johannesburg, Transvaal, South Africa: (or care of Messrs. Findlay, Durham and Brodie, 43–46 Threadneedle Street, London, E.C.)

1862. Reynolds, Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1879. Reynolds, George Bernard, Manager, Warora Colliery, Warora, Central Provinces, India.

1890. Rice, Thomas Sydney, Aldermary House, 60 Watling Street, London, E.C. [*Ricto, London.*]

1866. Richards, Edward Windsor, Low Moor Iron Works, near Bradford.

1882. Richards, George, Suffolk House, Laurence Pountney Hill, London, E.C.

1884. Richards, Lewis, 12 Park Villas, Llanishen, near Cardiff.

1863. Richardson, The Hon. Edward, C.M.G., Wellington, New Zealand.

1892. Richardson, Harry Alfred, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton.

1865. Richardson, John, Methley Park, near Leeds.

1873. Richardson, John, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1891. Richardson, John Scott, Box 13, Royal Exchange, Glasgow: (or care of J. W. Champness Richardson, Lindum, 23 Coleridge Road, Crouch End, London, N.)

1887. Richardson, Thomas, Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1874. Riches, Tom Hurry, Locomotive Superintendent, Taff Vale Railway, Cardiff. [*Locomotive, Cardiff.*]

1873. Rickaby, Alfred Austin, Bloomfield Engine Works, Sunderland. [*Rickaby, Sunderland.*]

1879. Ridley, James Cartmell, Swalwell Steel Works, Newcastle-on-Tyne.

1893. Ridley, James Taylor, 6 Ruthin Gardens, Cardiff.

1887. Riekie, John, District Locomotive Superintendent, North Western Railway, Quetta, Beluchistan, India.

1874. Riley, James, General Manager, Glasgow Iron and Steel Company, 1 St. Vincent Street, Glasgow.

1894. Riley, Joseph Hacking, Elton Iron Works, Bury, Lancashire.

1885. Ripley, Philip Edward, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich.

1884. Ripper, William, Professor of Mechanical Engineering, The Technical School, St. George's Square, Sheffield.

1889. Riva, Enrico, Locomotive and Carriage Superintendent, Ferrovie Meridionale, Bologna, Italy.

1879. Rixom, Alfred John, 108 Park Road, Loughborough.

1891. Roberts, Hugh Jorwerth, Messrs. Burn and Co., Howrah Iron Works, Howrah, Calcutta, India: (or care of R. P. Roberts, 3 Osborne Road, Liscard, near Liverpool.)

1887. Roberts, Thomas, Locomotive Engineer, Government Railways, Adelaide, South Australia.

1879. Roberts, Thomas Herbert, Mechanical Superintendent, Chicago and Grand Trunk Railway, Detroit, Michigan, United States.

1887. Roberts, William, 13 Craven Hill Gardens, Hyde Park, London, W.

1879. Robertson, William, Newlyn, Eton Avenue, Hampstead, London, N.W.

1894. Robinson, Arthur Maurice, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1894. Robinson, Charles John, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1890. Robinson, Frederick Arthur, Messrs. F. A. Robinson and Co., 54 Old Broad Street, London, E.C. [*Farrago, London.*]

1874. Robinson, Henry, Professor of Civil Engineering, King's College, Strand, London, W.C.; and 13 Victoria Street, Westminster, S.W.

1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow; and Westwood Hall, Leek, near Stoke-upon-Trent.

1886. Robinson, John, 8 Vicarage Terrace, Kendal.

1878. Robinson, John Frederick, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow.

1891. Robinson, John George, Locomotive and Carriage Engineer, Waterford and Limerick Railway, Limerick.

1892. Robinson, Leslie Stephen, 28 Victoria Street, Westminster, S.W. [*Eyebolts, London.*]

1894. Robinson, Mark Heaton, Messrs. Willans and Robinson, Ferry Works, Thames Ditton [*Willans, Thames-Ditton.*]; and Chatley, Fassett Road, Kingston-on-Thames.

1890. Robinson, Sydney Jessop, Messrs. W. Jessop and Sons, Brightside Steel Works, Sheffield.

1878. Robinson, Thomas Neild, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1891. Roche, Francis James, Shanghai Water Works, Shanghai, China.
1890. Rochford, John, Commissioners of Irish Lights, Westmoreland Street, Dublin.
1888. Rock, John William, Exchange Corner, Pitt Street, Sydney, New South Wales: (or care of E. G. Rock, The Red House, Ingatestone.)
1892. Rodgers, John, Messrs. J. S. Rodgers and Sons, Newcastle, New South Wales.
1872. Rofe, Henry, 8 Victoria Street, Westminster, S.W.
1885. Rogers, Henry John, Watford Iron Works, Watford. [*Engineer, Watford.*]
1887. Rogers, Horace Wyon, 43 Upper Thames Street, London, E.C.
1892. Ronald, Henry, Small Arms Ammunition Factory, Dum Dum, near Calcutta, India: (or care of James Ronald, 10 Campbell Terrace, Plumstead.)
1889. Rosenthal, James Hermann, Babcock and Wilcox Boiler Co., 147 Queen Victoria Street, London, E.C.
1881. Ross, William, Messrs. Ross and Walpole, North Wall Iron Works, Dublin. [*Iron, Dublin.* 311.]
1893. Rounthwaite, Henry Morrison, Messrs. Maudslay Sons and Field, 110 Westminster Bridge Road, London, S.E.; and 15 Nicosia Road, Wandsworth Common, London, S.W.
1856. Rouse, Frederick, Locomotive Department, Great Northern Railway, Peterborough.
1878. Routh, William Pole, Sutton Court, Sutton, Surrey.
1888. Rowan, James, Messrs. David Rowan and Son, Elliot Street, Glasgow.
1892. Rowe, Almond, Senior Government Marine Surveyor, Singapore, Straits Settlements.
1891. Rowland, Bartholomew Richmond, Messrs. Luke and Spencer, Ardwick, Manchester.
1867. Ruston, Joseph, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln; and 6 Onslow Gardens, South Kensington, London, S.W. [*Ruston, Lincoln.*]
1884. Rutherford, George, General Manager, Bute Shipbuilding Engineering and Dry Dock Co., Bute Dry Dock, Roath Basin, Cardiff. [*Caisson, Cardiff.*]
1885. Ryan, John, D.Sc., Professor of Physics and Engineering, University College, Bristol.
1866. Ryland, Frederick, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich.

1866. Sacré, Alfred Louis, 60 Queen Victoria Street, London, E.C. [*Sextant, London.* 1668.]
1864. Saïd, Colonel M., Pasha, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 108 Queen's Gate, London, S.W.)
1892. Sainsbury, Francis Charles Barrett, Messrs. John Jameson and Son, Bow Street Distillery, Dublin.

1859. Salt, George, Hope Cottage, Coleshill Road, Upper Teddington, Middlesex.
1874. Sampson, James Lyons, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N. [*Bascule, London.* 6699.]
1865. Samuelson, Sir Bernhard, Bart., M.P., F.R.S., Britannia Iron Works, Banbury; 56 Prince's Gate, South Kensington, London, S.W.; and Lupton, Brixham, South Devon.
1881. Samuelson, Ernest, Messrs. Samuelson and Co., Britannia Iron Works, Banbury.
1890. Sandberg, Christer Peter, 19 Great George Street, Westminster, S.W.
1881. Sanders, Henry Conrad, Messrs. H. G. Sanders and Son, Victoria Works, Victoria Gardens, Notting Hill Gate, London, W.; and Elm Lodge, Southall.
1871. Sanders, Richard David, Hartfield House, Eastbourne.
1886. Sandford, Horatio, Messrs. E. A. and H. Sandford, Thames Iron Works, Gravesend.
1881. Sandiford, Charles, Locomotive and Carriage Superintendent, North Western Railway, Lahore, Punjaub, India.
1891. Sands, Harold, 41 Widmore Road, Bromley, Kent.
1894. Sankey, Captain Matthew Henry Phineas Riall, Messrs. Willans and Robinson, Ferry Works, Thames Ditton. [*Willans, Thames-Ditton.*]
1874. Sauvée, Albert, 22 Parliament Street, Westminster, S.W. [*Sovez, London.* 3133.]
1891. Savill, Arthur Slater, Exhaust Steam Injector Company, 4 St. Ann's Square, Manchester.
1880. Saxby, John, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W. [*Signalmen, London.* 7068.]; and North Court, Hassocks, R.S.O., Sussex.
1893. Saxon, Alfred, Openshaw Engineering Works, Manchester. [*Saxons, Openshaw.* 959.]
1894. Saxon, George, Openshaw Engineering Works, Manchester. [*Saxons, Openshaw.* 959.]
1894. Saxon, James, Openshaw Engineering Works, Manchester. [*Saxons, Openshaw.* 959.]
1869. Scarlett, James, Messrs. E. Green and Son, 2 Exchange Street, Manchester; and Stamford Road, Bowdon, R.O., near Altrincham.
1890. Schofield, George Andrew, General Manager, Sicilian Railways, Palazzo Brijuccia, Palermo, Sicily: (or care of I. D. Schofield, Oakfield, Alderley Edge, Cheshire.)
1886. Scholes, William Henry, 1255 n/n Rivadavia, Buenos Aires, Argentine Republic: (or care of George Scholes, Orwell House, Upton Manor, Plaistow, London, E.)
1883. Schönheyder, William, 4 Rosebery Road, Brixton, London, S.W. [*Schönheyder, London.*]

1880. Schram, Richard, 17A Great George Street, Westminster, S.W. [*Schram, London.*]

1890. Schroller, William, 13 Old Elvet, Durham. [*Bulumatari, Durham.*]

1886. Schurr, Albert Ebenezer, Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.; and Lyncot, Leigh-on-Sea, Essex.

1885. Scorgie, James, Professor of Applied Mechanics, Civil Engineering College, Poona, India: Poona Villa, Beechgrove Terrace, Aberdeen: (or care of Messrs. W. Watson and Co., 27 Leadenhall Street, London, E.C.)

1891. Scott, Arthur Forbes, 69 Swan Arcade, Bradford.

1882. Scott, Charles Herbert, Messrs. Summers and Scott, High Orchard Iron Works, Gloucester.

1890. Scott, Frederick McClure, 89 Victoria Street, Liverpool.

1891. Scott, F. Walter, Messrs. George Scott and Son, 44 and 46 Christian Street, London, E. [*Thirty-four, London.* 4390.]

1875. Scott, Frederick Whitaker, Atlas Steel and Iron Wire Rope Works, Reddish, Stockport. [*Atlas, Reddish.*]

1891. Scott, Henry John, Glendon Engine Works, Kettering. [*Engine, Kettering.*]

1877. Scott, Irving M., Union Iron Works, San Francisco, California.

1881. Scott, James, General Manager, President Land and Exploration Co., Pretoria, Transvaal, South Africa: (or Douglasfield, Murthly, Perthshire.)

1886. Scott, James, Consett Iron Works, Consett, R.S.O., County Durham.

1894. Scott, Robert, H. M. Mint, Calcutta, India.

1891. Scott, Robert Julian, Professor of Engineering, New Zealand University, Canterbury College, Christchurch, New Zealand.

1861. Scott, Walter Henry, Park Road, East Molesey, near Kingston-on-Thames.

1884. Scott-Moncrieff, William Dundas, 14 Victoria Street, Westminster, S.W.

1882. Seabrook, Alfred William, Engineer Surveyor to the Port of Bombay, Port Office, Bombay; and care of Sam Brownson, 1 Laurel Villas, Bedonwell Hill, Belvedere, Kent.

1892. Seaman, Charles Joseph, Stockton Forge Works, Stockton-on-Tees. [*Forge, Stockton-on-Tees.*]

1882. Seaton, Albert Edward, Earle's Shipbuilding and Engineering Works, Hull.

1886. Seddon, Robert Barlow, Hall Lane, Hindley, near Wigan.

1891. Selby, Millin, 14 Rue de la Gare, Lille, France.

1882. Selfe, Norman, 279 George Street, Sydney, New South Wales.

1884. Sellers, Coleman, E.D., Professor of Engineering, Stevens Institute, and Franklin Institute; 3301 Baring Street, Philadelphia, Pennsylvania, United States.

1888. Sellers, George, 24 Bradfield Road, Owlerton, Sheffield.

1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania, United States.

1891. Sellier, Alphonse Louis, 74 St. James' Street, Sanfernando, Trinidad.

1894. Seymour, Louis Irving, 43 Threadneedle Street, London, E.C. [*Nioga, London.* 11,168.]

1883. Shackleford, Arthur Lewis, General Manager, Britannia Railway-Carriage and Wagon Works, Saltley, Birmingham.

1884. Shackleford, William Copley, Manager, Lancaster Wagon Works, Lancaster; and 6 Victoria Street, Westminster, S.W.

1894. Shand, John, Messrs. Bertrams, St. Katherine's Works, Sciennes, Edinburgh.

1872. Shanks, Arthur, Fairmile, Cobham, Surrey.

1884. Shanks, William, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]

1881. Shapton, William, Sir William G. Armstrong, Mitchell and Co., 8 Great George Street, Westminster, S.W.

1890. Shardlow, Ambrose, Ealing Works, Washford Road, Attercliffe, Sheffield.

1891. Sharp, Henry, 23 College Hill, London, E.C.; and 1 Whitehall Gardens, London, S.W.

1875. Sharp, Thomas Budworth, Consulting Engineer, Muntz Metal Works, Birmingham; and County Chambers A, Martineau Street, Birmingham. [*Budworth, Birmingham.*]

1881. Shaw, Joshua, Messrs. John Shaw and Sons, Wellington Street Works, Salford, Manchester.

1881. Shaw, William, Messrs. W. Shaw Kirtley and Co., Wellington Cast Steel Foundry, Middlesbrough.

1890. Sheldon, Harry Cecil, Messrs. W. P. Thompson and Boult, 63 Long Row, Nottingham.

1891. Shenton, James, Messrs. Tinker Shenton and Co., Hyde Boiler Works, Hyde, near Manchester.

1892. Shepherd, James, Messrs. Davy Brothers, Park Iron Works, Sheffield.

1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.

1875. Sheppard, Herbert Gurney, Chief Engineer, Assioot-Girgeh Railway, Assioot, Upper Egypt: (or 89 Westbourne Terrace, Hyde Park, London, W.)

1876. Shield, Henry, Messrs. Fawcett Preston and Co., Phœnix Foundry, 17 York Street, Liverpool.

1888. Shin, Tsuneta, Director, Ishikawajima Shipbuilding and Engineering Co., Tokyo, Japan.

1892. Shirlaw, Andrew, Suffolk Works, Oozells Street, Birmingham. [*Shirlaw, Birmingham.*]

1889. Shone, Isaac, 47 Victoria Street, Westminster, S.W.

1890. Shoosmith, Harry, Messrs. Priestman Brothers, Holderness Foundry, Hull.

1890. Shore, Alfred Thomas, Government Inspector of Steam Boilers, Custom House, Bombay, India.

1893. Shroff, Adurjee Burjorjee, Chief Engineer, Sassoon Spinning Mills, Bombay, India.

1885. Shuttleworth, Alfred, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln. [*Claytons, Lincoln.*]

1885. Shuttleworth, Major Frank, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln; and Old Warden Park, Biggleswade. [*Claytons, Lincoln.*]

1891. Siemens, Alexander (*Life Member*), 12 Queen Anne's Gate, Westminster, S.W.

1888. Siemens, Frederick, 10 Queen Anne's Gate, Westminster, S.W.

1871. Simon, Henry, 20 Mount Street, Manchester. [*Reform, Manchester.*]

1877. Simonds, William Turner (*Life Member*), Messrs. J. C. Simonds and Son, Oil Mills, Boston.

1876. Simpson, Arthur Telford, Engineer, Chelsea Water Works, 38 Parliament Street, Westminster, S.W.

1883. Simpson, Charles Liddell, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W. [*Aquosity, London.*]

1885. Simpson, James Thomas, Executive Engineer, Henzada Division, Henzada, Burma.

1882. Simpson, John Harwood, Manchester Ship Canal, 65 King Street, Manchester.

1889. Sinclair, Nisbet, The William Cramp and Sons Ship and Engine Building Co., Philadelphia, Pennsylvania, United States.

1847. Sinclair, Robert, care of Messrs. Sinclair Hamilton and Co., 17 St. Helen's Place, Bishopsgate Street, London, E.C. [*Sinclair, London.*]

1891. Sinclair, Russell, Messrs. J. Wildridge and Sinclair, 97 Pitt Street, Sydney, New South Wales.

1881. Sisson, William, Quay Street Iron Works, Gloucester. [*Sisson, Gloucester.*]

1872. Slater, Alfred, Gloucester Wagon Works, Gloucester.

1892. Slight, George Henry, Sub-Director of Lighthouses, Valparaiso, Chile: (or care of George H. Slight, Sen., Brook Cottage, Ashburton, Devonshire.)

1885. Slight, William Hooper, Lidgerwood Manufacturing Co., Soerabaya, Java: (or care of G. H. Slight, 64 Cromwell Road, Fitzhugh, Southampton.)

1891. Sloan, Robert Alexander, Messrs. Sloan and Lloyd Barnes, Castle Chambers, 26 Castle Street, Liverpool. [*Technical, Liverpool.*]

1886. Small, James Miln, Messrs. Urquhart and Small, 17 Victoria Street, Westminster, S.W.

1889. Smelt, John Dann, Argentine Great Western Railway, 4 Finsbury Circus, London, E.C.

1879. Smith, Charles Hubert, Board of Trade Surveyors' Office, Leith.

1860. Smith, Henry, Messrs. Hill and Smith, Brierley Hill Iron Works, Brierley Hill; and Summerhill, Kingswinford, near Dudley. [*Fencing, Brierley Hill.*]

1881. Smith, Henry, Messrs. Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.

1860. Smith, Sir John, Parkfield, Duffield Road, Derby.

1876. Smith, John, Wintoun Terrace, Rochdale.

1893. Smith, John, Salford Works, Richard Street, Birmingham.

1883. Smith, John Bagnold, Newstead Colliery, near Nottingham.

1891. Smith, John Reney, Messrs. Harvey and Bower, 16 Seaton Buildings, 17 Water Street, Liverpool. [*Inspecting, Liverpool.* 6204.]

1890. Smith, John Windle, Messrs. Thomas Drysdale and Co., 438 Calle Moreno, Buenos Aires, Argentine Republic: (or care of Edward Smith, The "Lock," Gainsborough.)

1857. Smith, Josiah Timmis, Hæmatite Iron and Steel Works, Barrow-in-Furness; and Rhine Hill, Stratford-on-Avon.

1870. Smith, Michael Holroyd, Royal Insurance Buildings, Crossley Street, Halifax; and 18 Abingdon Street, Westminster, S.W. [*Outfall, London.*]

1886. Smith, Reginald Arthur, Messrs. Dorman and Smith, Ordsal Station Electrical Works, Salford, Manchester.

1881. Smith, Robert Henry, Professor of Engineering, Mason Science College, Birmingham; and 124 Hagley Road, Edgbaston, Birmingham.

1885. Smith, Thomas, Steam Crane Works, Old Foundry, Rodley, near Leeds. [*Tomsmith, Leeds.*]

1890. Smith, Thomas Ridsdill, Messrs. Browett Lindley and Co., Patricroft, near Manchester.

1881. Smith, Wasteneys, 59 Sandhill, Newcastle-on-Tyne. [*Wasteneys Smith, Newcastle-on-Tyne.* 429.]

1890. Smith, William, London and Manchester Plate Glass Co., Sutton, St. Helen's, Lancashire.

1894. Smith, William, Roads Bridges and Sewerage Department, Sewerage Construction Branch, Public Works Office, Sydney, New South Wales.

1863. Smith, William Ford, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester. [*Gresley, Manchester.* 564.]

1887. Smith, William Mark, District Locomotive Carriage and Wagon Superintendent, Great Southern and Western Railway, Cork.

1882. Smyth, James Josiah, Messrs James Smyth and Sons, Peasenhall, Suffolk.

1884. Smyth, William Stopford, Engineer, Alexandra Docks, Newport, Monmouthshire.

1883. Snelus, George James, F.R.S., Ennerdale Hall, Frizington, near Carnforth.

1885. Snowdon, John Armstrong, Stanners Closes Steel Works, Wolsingham, near Darlington.

1887. Sorabji, Shapurji, Messrs. Shapurjee and Ratanshaw, 1 and 2 West India House, Leadenhall Street, London, E.C.

1884. Soulsby, James Charlton, 14 Ruthin Gardens, Cathays, Cardiff.

1889. Souter-Robertson, David, Assistant Superintendent, Government Canal Foundry and Workshops, Roorkee, North Western Provinces, India.

1885. Southwell, Frederick Charles, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.

1877. Soyres, Francis Johnstone de, 4 Arlington Villas, Clifton, near Bristol.

1893. Spence, Arthur William, Manager, Cork Street Foundry and Engineering Works, Dublin.

1887. Spence, William, Cork Street Foundry and Engineering Works, Dublin.

1887. Spencer, Alexander, Messrs. George Spencer, Moulton and Co., 77 Cannon Street, London, E.C. [*George Spencer, London.*]

1878. Spencer, Alfred G., Messrs. George Spencer, Moulton and Co., 77 Cannon Street, London, E.C. [*George Spencer, London.*]

1892. Spencer, Henry Bath, British Steam Users' Insurance Society, Manchester; and 42 Lansdowne Road, Didsbury, Manchester.

1877. Spencer, John, Globe Tube Works, Wednesbury; and 14 Great St. Thomas Apostle, London, E.C. [*Tubes, Wednesbury. Tubes, London.* 6504.]

1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne. [*Newburn, Newcastle-on-Tyne.*]

1885. Spencer, Mountford, Messrs. Luke and Spencer, Ardwick, Manchester; and The Hill, Teignmouth.

1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne. [*Newburn, Newcastle-on-Tyne.*]

1891. Spencer, William, Messrs. James Spencer and Co., Chamber Iron Works, Hollinwood, near Manchester.

1885. Spooner, George Percival, Locomotive Superintendent, Bolan Railway, Hirokh, Beluchistan, India; and Whitehall Club, Parliament Street, Westminster, S.W.

1883. Spooner, Henry John, 309 Regent Street, London, W.

1869. Stabler, James, 13 Effra Road, Brixton, London, S.W.

1877. Stanger, George Hurst, Queen's Chambers, North Street, Wolverhampton.

1875. Stanger, William Harry, Chemical Laboratory and Testing Works, Broadway, Westminster, S.W. [3117.]

1888. Stanley, Harry Frank, Messrs. Pontifex and Wood, Farringdon Works, Shoe Lane, London, E.C.; and 84 Finsbury Park Road, London, N.

1888. Stannah, Joseph, 20 Southwark Bridge Road, London, S.E.

1884. Stanton, Frederic Barry, 18 Bishopsgate Street Within, London, E.C. [*Barry Stanton, London.* 4084.]

1874. Stephens, Michael, Chief Locomotive Superintendent of the Government Railways, Cape Town, Cape of Good Hope.

1868. Stephenson, George Robert, Ben Braich, Tilehurst Road, Reading.

1879. Stephenson, Joseph Gurdon Leycester, 6 Drapers' Gardens, London, E.C. [*Fluvius, London.*]

1888. Stephenson-Peach, William John, Askew Hill, Repton, Burton-on-Trent.

1876. Sterne, Louis, Messrs. L. Sterne and Co., Crown Iron Works, Glasgow [*Crown, Glasgow.*]; and 28 Victoria Street, Westminster, S.W. [*Elsterne, London.* 3066.]

1891. Stevens, James, 9 and 11 Fenchurch Avenue, London, E.C.

1894. Stevens, Thomas, Ceres Iron Works, Kingston-on-Thames.

1887. Stevenson, David Alan, F.R.S.E., 84 George Street, Edinburgh.

1892. Stevinson, Thomas, Messrs. Hender and Stevinson, Nailsworth, near Stroud, Gloucestershire.

1893. Steward, George Richard, 15 Queen Street, Queen Victoria Street, London, E.C.

1877. Stewart, Alexander, Messrs. Thornton and Crebbin, Hammerton Street Iron Works, Bradford; and 3 Southbrook Terrace, Bradford.

1887. Stewart, Andrew, 41 Oswald Street, Glasgow.

1878. Stewart, Duncan, Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow. [*Stewart, Glasgow.* 531.]

1851. Stewart, John, Blackwall Iron Works, Poplar, London, E. [*Steamships, London.*]; and 8 Stamford Avenue, Preston Park, Brighton.

1888. Stiff, William Charles, 75 Hagley Road, Edgbaston, Birmingham.

1892. Still, William Henry, Aden, Arabia.

1880. Stirling, James, Locomotive Superintendent, South Eastern Railway, Ashford, Kent.

1885. Stirling, Matthew, Locomotive Superintendent, Hull Barnsley and West Riding Junction Railway and Dock Co., Hull.

1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Railway, Doncaster.

1888. Stirling, Robert, Locomotive Department, North Eastern Railway, Gateshead.

1875. Stoker, Frederick William, 6 Consolidated Gold Fields Buildings, P.O. Box 855, Johannesburg, Transvaal, South Africa.

1877. Stokes, Alfred Allen, Elmcote, Godalming.

1892. Stone, Edward Herbert, District Engineer, East Indian Railway, Asansol, India.

1887. Stone, Frank Holmes, P.O. Box, Kingston, Jamaica.

1877. Stothert, George Kelson, Steam Ship Works, Bristol.
1888. Strachan, James, 70 Frederick Street, Gray's Inn Road, London, W.C.
1892. Strachan, John, 29 The Walk, Cardiff.
1888. Straker, Sidney, Messrs. Straker Whitworth and Co., 139 Cannon Street, London, E.C. [*Rhomboidal, London.*]; and 240 Stanstead Road, Forest Hill, London, S.E.
1884. Stronge, Charles, Locomotive Department, Porto Alegre and New Hamburg Railway, São Leopoldo, Rio Grande do Sol, Brazil: (or 1 Albion Street, Hyde Park, London, W.)
1873. Strype, William George, 115 Grafton Street, Dublin. [*Strype, Dublin.*]
1890. Stutzer, Waldemar, Koltchugin Brass and Copper Mill Co., Alexandrov Station, Jaroslav Railroad, Russia.
1882. Sugden, Thomas, Babcock and Wilcox Co., 147 Queen Victoria Street, London, E.C.
1890. Sulzer, Jacob, Messrs. Sulzer Brothers, Winterthur, Switzerland.
1861. Sumner, William, 2 Brazennose Street, Manchester.
1875. Sutcliffe, Frederic John Ramsbottom, Engineer, Low Moor Iron Works, near Bradford.
1883. Sutton, Joseph Walker, 36 Bedford Street, Strand, London, W.C.
1880. Sutton, Thomas, Carriage and Wagon Superintendent, Furness Railway, Barrow-in-Furness.
1882. Swaine, John, 9 Miles Road, Clifton, Bristol.
1884. Swan, Joseph Wilson, F.R.S., 57 Holborn Viaduct, London, E.C.; and Lauriston, Bromley, Kent.
1882. Swinburne, Mark William, Wallsend Brass Works, Newcastle-on-Tyne; and 117 Park Road, Newcastle-on-Tyne. [*Bronze, Wallsend.*]
1864. Swindell, James Swindell Evers, Homer Hill, Cradley, Staffordshire.
1890. Swinerd, Edward, Superintendent, Locomotive Carriage and Wagon Departments, Mogyana Railway, Campinas, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, Laurence Pountney Hill, London, E.C.)
1890. Swinnerton, Robert Allen William, Executive Engineer, Public Works Department, Bolarum, Dekkan, India: (or care of Messrs. Henry S. King and Co., 65 Cornhill, London, E.C.)

1878. Taite, John Charles, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C. [1618.]; and The Corner House, Shortlands, S.O., Kent.
1882. Tandy, John O'Brien, Locomotive Department, London and North Western Railway, Crewe; and 4 Wellington Villas, Wellington Square, Crewe.
1875. Tangye, George, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham. [*Tangyes, Birmingham.*]

1889. Tangye, Harold Lincoln, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.

1861. Tangye, James, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham; and Aviary Cottage, Illogan, near Redruth.

1879. Tartt, William, Maythorn, Blindley Heath, Godstone, near Red Hill.

1893. Tasker, Frederick, Messrs. Tasker Sons and Co., New Station Road, Sheffield. [*Tasker, Sheffield.* 1005.]

1876. Taunton, Richard Hobbs, 10 Coleshill Street, Birmingham.

1874. Taylor, Arthur, Manager, Sociedad Anglo-Vasca, Villanueva del Duque, Provincia de Cordoba, Spain: (or 21 Victoria Road, Kensington, London, W.)

1873. Taylor, John, Midland Foundry, Queen's Road, Nottingham.

1875. Taylor, Joseph Samuel, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham. [*Derwent, Birmingham.*]

1874. Taylor, Percyvale, Messrs. Burthe and Taylor, Paris; and 21 Victoria Road, Kensington, London, W.

1893. Taylor, Robert, Jun., Works Manager, Messrs. Asa Lees and Co., Soho Iron Works, Oldham.

1882. Taylor, Robert Henry, 2 Winchester Terrace, Newcastle-on-Tyne.

1882. Taylor, Thomas Albert Oakes, Messrs. Taylor Brothers and Co., Clarence Iron and Steel Works, Leeds.

1864. Tennant, Sir Charles, Bart. (*Life Member*), The Glen, Innerleithen, near Edinburgh.

1882. Terry, Stephen Harding, 17 Victoria Street, Westminster, S.W.

1891. Tetlow, Ernest, Messrs. Tetlow Brothers, Bottoms Iron Works, Hollinwood, near Manchester.

1877. Thom, William, Messrs. Yates and Thom, Canal Foundry, Blackburn.

1889. Thomas, James Donnithorne, 25A Old Broad Street, London, E.C. [*Kooringa, London.*]

1867. Thomas, Joseph Lee, 2 Hanover Terrace, Ladbroke Square, Notting Hill, London, W.

1888. Thomas, Philip Alexander, The Decatur Mines Syndicate, 608 and 609 Boston Buildings, Denver, Colorado, United States.

1864. Thomas, Thomas, 10 Richmond Road, Roath, Cardiff.

1874. Thomas, William Henry, 15 Parliament Street, Westminster, S.W.

1891. Thompson, James, Highfield Boiler Works, Ettingshall, Wolverhampton. [*Boiler, Wolverhampton.*]

1875. Thompson, John, Highfield Boiler Works, Ettingshall, Wolverhampton. [*Boiler, Wolverhampton.*]

1883. Thompson, Richard Charles, Messrs. Robert Thompson and Sons, Southwick Shipbuilding Yard, Sunderland.

1880. Thompson, Thomas William, Eastham Ferry Pier, near Birkenhead.

1887. Thompson, William Phillips, 6 Lord Street, Liverpool.

1875. Thomson, James McIntyre, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow. [*Engineering, Glasgow.*]

1868. Thomson, John, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow [*Engineering, Glasgow.*]; and 3 Crown Terrace, Dowanhill, Glasgow.

1889. Thomson, Robert McNider, Kobe Engine Works, Kobe, Japan: (or care of William Hipwell, Hillside House, Sharnbrook, Bedford.)

1893. Thornbery, William Henry, Jun., 38 Bennett's Hill, Birmingham. [*Engineer, Birmingham.* 113.]

1868. Thornewill, Robert, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1885. Thornley, George, Messrs. Buxton and Thornley, Waterloo Engineering Works, Burton-on-Trent.

1877. Thornton, Frederic William, care of The Hydraulic Engineering Co., Chester.

1882. Thornton, Hawthorn Robert, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1888. Thornton, Robert Samuel, West's Patent Press Co., Etawah, North Western Provinces, India.

1876. Thornycroft, John Isaac, F.R.S., Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W. [*Thornycroft, London.*]

1882. Thow, William, Locomotive Engineer, New South Wales Government Railways, Eveleigh Workshops, Sydney, New South Wales: (or care of Joseph Meilbek, 13 Victoria Street, Westminster, S.W.)

1891. Tilley, Albert, care of Bernard Dawson, York House, Malvern Link, Malvern.

1885. Timmermans, François, Managing Director, Société anonyme des Ateliers de la Meuse, Liége, Belgium. [*Société Meuse, Liége.*]

1884. Timmis, Illius Augustus, 2 Great George Street, Westminster, S.W. [*Timmis, London.*]

1886. Tipping, Henry, 58 South Street, Greenwich, London, S.E.

1890. Titley, Arthur, Beechwood, Hartopp Road, Four Oaks, Sutton Coldfield, near Birmingham.

1888. Todd, Robert Ernest, Mechanical Engineer, Tucuman, Estacion Provincia, Argentine Republic: (or care of William H. Todd, County Buildings, Land of Green Ginger, Hull.)

1875. Tomkins, William Steele, Messrs. Sharp Stewart and Co., Atlas Works Glasgow; and 28 Victoria Street, Westminster, S.W.

1857. Tomlinson, Joseph, 64 Priory Road, West Hampstead, London, N.W.

1888. Topple, Charles James, Machinery Department, Royal Arsenal, Woolwich.

1894. Touch, John Edward, 34 Victoria Street, Westminster, S.W.

1883. Tower, Beauchamp, 5 Queen Anne's Gate, Westminster, S.W.

1889. Towler, Alfred, Messrs. Hathorn Davey and Co., Sun Foundry, Leeds.

1886. Towne, Henry Robinson, Yale and Towne Manufacturing Co., Stamford, Connecticut, United States.

1893. Townsend, C. Collingwood, Captain R.A., Superintendent, Gun-Carriage Factory, Madras, India.

1890. Trail, John, Marine Superintendent, Knott's Prince Line of Steamers, Newcastle-on-Tyne.

1888. Travis, Henry, Assistant Superintending Engineer and Constructor of Shipping to the War Department, Royal Arsenal, Woolwich.

1889. Treharne, Gwilym Alexander, Pontypridd; and Aberdare.

1889. Trenery, William Penrose, 73 Via Milano, Genoa, Italy.

1883. Trentham, William Henry, 39 Victoria Street, Westminster, S.W.

1876. Trevithick, Richard Francis, Locomotive and Carriage Superintendent, Japanese Government Railways, Kobe, Japan: (or care of Mrs. Mary Trevithick, The Cliff, Penzance.)

1886. Trew, James Bradford, High Street, Watford, Herts.

1887. Trier, Frank, Messrs. Brunton and Trier, 19 Great George Street, Westminster, S.W.

1885. Trueman, Thomas Brynalyn, Hotel del Norte, Paseo de Julio Esquina, Corrientes, Buenos Aires, Argentine Republic: (or care of Thomas R. Trueman, 3 The Barons, Twickenham.)

1887. Turnbull, Alexander, Messrs. Alexander Turnbull and Co., St. Mungo Works, Bishopbriggs, Glasgow. [*Valve, Glasgow.* 1270.]

1885. Turnbull, John, Jun., 18 Blythswood Square, Glasgow. [*Turbine, Glasgow.* 59.]

1894. Turner, Albert, Whitehouse Machine Works, Denton, near Manchester. [*Machines, Denton.* 5.]

1866. Turner, Frederick, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich. [*Gippeswyk, Ipswich.*]

1887. Turner, Joshua Alfred Alexander, Inspector, Commissariat Mills and Bakeries, Bombay Presidency, Poona, India.

1882. Turner, Thomas, Havelock House, Shelton, Stoke-on-Trent.

1886. Turner, Tom Newsum, Vulcan Iron Works, Langley Mill, near Nottingham.

1876. Turney, Sir John, Messrs. Turney Brothers, Trent Bridge Leather Works, Nottingham. [*Turney, Nottingham.*]

1891. Tweddell, Ralph Hart, 14 Delahay Street, Westminster, S.W. [*Tweddell, Westminster, London.*]

1882. Tweedy, John, Messrs. Wigham Richardson and Co., Newcastle-on-Tyne.
1856. Tyler, Sir Henry Whatley, K.C.B., Pymmes Park, Edmonton, Middlesex.
1877. Tylor, Joseph John, 2 Newgate Street, London, E.C.
1889. Tyrrell, Joseph John, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.

1878. Unwin, William Cawthorne, F.R.S., Professor of Engineering, City and Guilds of London Central Institution, Exhibition Road, London, S.W.; and 7 Palace Gate Mansions, Kensington, London, W.
1875. Urquhart, Thomas, Delny House, Delny, R.S.O., Ross-shire.

1880. Valon, William Andrew McIntosh, 140 and 141 Temple Chambers, Temple Avenue, London, E.C.; and Ramsgate. [*Valon, Ramsgate.*]
1885. Vaughan, William Henry, Royal Iron Works, West Gorton, Manchester. [*Vaunting, Manchester.* 5106.]
1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.; and Rothbury, Blackheath Park, London, S.E. [*Exemplar, London.*]
1889. Vesian, John Stuart Ellis de, 5 Crown Court, Cheapside, London, E.C. [*Biceps, London.*]
1891. Vicars, John, Gillbank, Boot, viâ Carnforth.
1865. Vickers, Albert, Messrs. Vickers Sons and Co., River Don Works, Sheffield.
1861. Vickers, Thomas Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.
1888. Voysey, Henry Wesley, 1 Fordwych Road, Brondesbury, London, N.W.

1883. Waddell, James, 9 Ashton Terrace, Dowanhill, Glasgow.
1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.
1879. Wadia, The Hon. Nowrosjee Nesserwanjee, C.I.E., Manager, Manockjee Petit Manufacturing Co., Tardeo, Bombay: (or care of Messrs. Hick Hargreaves and Co., Soho Iron Works, Bolton.) [*Wadia, Tardeo, Bombay.*]
1882. Wailes, George Herbert, St. Andrews, Watford, Herts.
1875. Wailes, John William, South Shore, Gateshead-on-Tyne.
1884. Wailes, Thomas Waters, General Manager, Mountstuart Dry Dock and Engineering Works, Cardiff. [*Mountstuart, Cardiff.*]
1888. Waister, William Henry, Assistant Locomotive Superintendent, Great Western Railway, Stafford Road Works, Wolverhampton.
1881. Wake, Henry Hay, Engineer to the River Wear Commission, Sunderland.
1882. Wakefield, William, 123 Rathgar Road, Dublin.

1892. Waldron, Patrick Lawrence, R.N.R., Irish Lights Service, Castletown Berehaven, Co. Cork, Ireland; and 24 St. Joseph's Road, Aughrim Street, Dublin.

1891. Walker, Arthur Tannett, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds.

1875. Walker, George, 95 Leadenhall Street, London, E.C.

1890. Walker, Henry, 11 Oxford Terrace, Gateshead.

1894. Walker, Henry Claude, Messrs. R. Waygood and Co., Falmouth Road, Great Dover Street, London, S.E. [*Waygood, London.* 4760.]

1875. Walker, John Scarisbrick, Messrs. J. S. Walker and Brother, Pagefield Iron Works, Wigan; and 3 Alexandra Road, Southport. [*Pagefield, Wigan.*]

1884. Walker, Sydney Ferris, Cardiff Electrical Works, Severn Road, Cardiff [*Dynamo, Cardiff.*]; and Hunter's Forge, New Bridge Street, Newcastle-on-Tyne. [*Dynamo, Newcastle-on-Tyne.*]

1876. Walker, Thomas Ferdinand, Ship's Log Manufacturer, 58 Oxford Street, Birmingham.

1878. Walker, William, Kaliemaas, Alleyne Park, West Dulwich, London, S.E. [*Bromo, London.*]

1890. Walker, William George, 47 Victoria Street, Westminster, S.W.

1878. Walker, Zaccheus, Jun., Fox Hollies Hall, near Birmingham.

1884. Wallace, John, Backworth Collieries, near Newcastle-on-Tyne.

1884. Wallau, Frederick Peter, Messrs. Harland and Wolff, Belfast.

1868. Wallis, Herbert, Mechanical Superintendent, Grand Trunk Railway, Montreal, Canada.

1893. Wallwork, Roughsedge, Union Bridge Iron Works, Charter Street, Manchester.

1891. Walmsley, John, Queen's Mills, Huddersfield.

1865. Walpole, Thomas, Messrs. Ross and Walpole, North Wall Iron Works, Dublin. [*Iron, Dublin.* 311.]

1877. Walton, James, 28 Maryon Road, Charlton, Kent.

1881. Warburton, John Seaton, 19 Stanwick Road, West Kensington, London, W.

1882. Ward, Thomas Henry, 24 Church Lane, Smethwick, near Birmingham.

1876. Ward, William Meese, Newton Villa, Claremont Road, Handsworth, R.O., near Birmingham.

1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Handsworth, R.O., near Birmingham. [*Bolts, Birmingham.*]

1882. Wardle, Edwin, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds. [*Manning, Leeds.*]

1886. Warren, Frank Llewellyn, 73 Breakspears Road, St. John's, London, S.E.

1885. Warren, Henry John, Jun., Cornwall Boiler Works, Camborne.

1885. Warren, William, Chief Engineer, Midland Uruguay Railway, Paysandu, Uruguay: (or care of Walter Ross, Hill Top, Blythe Hill, Catford, London, S.E.)

1889. Warsop, Thomas, Coniston Copper Mines, Coniston, S.O., Lancashire.

1858. Waterhouse, Thomas (*Life Member*), Claremont Place, Sheffield.

1891. Waterous, Julius E., Waterous Engine Works Co., Brantford, Ontario, Canada.

1881. Watkins, Alfred, 58 Fenchurch Street, London, E.C.

1862. Watkins, Richard, 71 Blenheim Crescent, London, W.

1890. Watkinson, William Henry, Professor of Motive Power Engineering, Glasgow and West of Scotland Technical College, 38 Bath Street, Glasgow.

1890. Watson, George Coghlan, Manganese Bronze and Brass Co., St. George's Wharf, Deptford, London, S.E.; and Granville House, Bedford Park, Croydon.

1882. Watson, Henry Burnett, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne. [*Watsons, Newcastle-on-Tyne.* 439.]

1879. Watson, Sir William Renny, 16 Woodlands Terrace, Glasgow.

1891. Watt, Charles, 418 Little Collins Street, Melbourne, Victoria.

1877. Watts, John, Broad Weir Engine Works, Bristol.

1886. Weatherburn, Robert, Locomotive Manager, Midland Railway Works, Kentish Town, London, N.W.

1894. Webb, Henry, Messrs. Joseph Webb and Co., Irwell Forge and Rolling Mills, Bury, Lancashire.

1884. Webb, Richard George, Messrs. Richardson and Cruddas, Byculla Iron Works, Bombay, India: (or care of Messrs. Richardson and Hewett, 101 Leadenhall Street, London, E.C.)

1890. Webster, John James, 39 Victoria Street, Westminster, S.W.

1887. Webster, William, 6 Oxley Road, Singapore, Straits Settlements.

1883. Weck, Friedrich, Lilleshall Old Hall, near Newport, Shropshire.

1891. Weightman, Walter James, Engineer-in-Chief, Nilgiri Railway, Coonoor, Madras, India.

1888. Wellman, Samuel T., Upland, Delaware County, Pennsylvania, United States.

1882. West, Charles Dickinson, Professor of Mechanical Engineering, Imperial College of Engineering, Tokyo, Japan.

1876. West, Henry Hartley, Naval Architect and Engineer, 5 Castle Street, Liverpool. [*Referee, Liverpool.* 5223.]

1894. West, James, Post Office, Koffyfontein Mines, Orange Free State, South Africa.

1894. West, John, Albion Iron Works, Miles Platting, Manchester.

1891. West, Leonard, Ravenhead Plate Glass Works, St. Helen's, Lancashire.

1874. West, Nicholas James, Messrs. Harvey and Co., 186 Gresham House, Old Broad Street, London, E.C.; and The Turret, West Heath Road, Hampstead, London, N.W.

1877. Western, Charles Robert, Broadway Chambers, Westminster, S.W. [*Donbowes, London.* 3199.]

1877. Western, Maximilian Richard, care of Colonel Western, C.M.G., Broadway Chambers, Westminster, S.W.

1862. Westmacott, Percy Graham Buchanan, Sir W. G. Armstrong Mitchell and Co., Elswick Engine Works, Newcastle-on-Tyne; and Benwell Hill, Newcastle-on-Tyne.

1880. Westmoreland, John William Hudson, Lecturer on Engineering, University College, Nottingham.

1880. Westwood, Joseph, Napier Yard, Millwall, London, E. [*Westwood, London.* 5065.]

1888. Weyman, James Edwardes, Messrs. Weyman and Hitchcock, Trusty Engine Works, Cheltenham; and Chadborne, Christ Church Road, Cheltenham.

1884. Whieldon, John Henry, 75 Ivydale Road, Nunhead, London, S.E.

1894. Whitby, Arthur George, The Limes, Amersham.

1882. White, Alfred Edward, Borough Engineer's Office, Town Hall, Hull.

1887. White, Alfred George, 11 Queen Victoria Street, London, E.C.

1888. White, William Henry, C.B., LL.D., F.R.S., Assistant Controller and Director of Naval Construction, Admiralty, Whitehall, London, S.W.

1890. Whitehouse, Edwin Edward Joseph, Monkbridge Iron Works, Leeds.

1876. Whiteley, William, Holly Mount, Edgerton, Huddersfield.

1891. Whittaker, John, Messrs. William Whittaker and Sons, Sun Iron Works, Oldham.

1869. Whittem, Thomas Sibley, Wyken Colliery, Coventry.

1878. Whytehead, Hugh Edward, Meadowside, Mayfield Road, Moseley, Birmingham.

1878. Wicks, Henry, Messrs. Burn and Co., Howrah Iron Works, Howrah, Bengal, India: (or care of John Spencer, 125 West Regent Street, Glasgow.)

1868. Wicksteed, Joseph Hartley, Messrs. Joshua Buckton and Co., Well House Foundry, Meadow Road, Leeds.

1891. Widdowson, John Henry, Britannia Works, Ordsal Lane, Salford, Manchester.

1878. Widmark, Harald Wilhelm, Helsingborgs Mekaniska Verkstad, Helsingborg, Sweden.

1889. Wigham, John Richardson, Messrs. J. Edmundson and Co., Stafford Works, 35 Capel Street, Dublin.

1881. Wigzell, Eustace Ernest, Billiter House, Billiter Street, London, E.C. [*Wigzell, London.* 1844.]

1890. Wild, John, Falcon Iron Works, Oldham. [*Falcon, Oldham.*]

1886. Wildridge, John, Messrs. J. Wildridge and Sinclair, 97 Pitt Street, Sydney, New South Wales: (or care of R. Wildridge, 624 Cathcart Road, Govanhill, Glasgow.)

1890. Wildy, William Lawrence, 42 North Parade, Grantham.

1892. Wilkinson, Edward R., 63 Middle Lane, Hornsey, London, N.

1885. Willcox, Francis William, 45 West Sunniside, Sunderland.

1893. Williams, Arthur Edward, Resident Engineer, Dagenham Dock, Essex.

1883. Williams, Sir Edward Leader, Engineer, Manchester Ship Canal Co., 41 Spring Gardens, Manchester. [*Leader, Manchester.* 688.]

1884. Williams, John Begby, Central Marine Engine Works, West Hartlepool.

1885. Williams, Nicholas Thomas, General Manager, Witwatersrand Gold Mine, P.O. Box 1019, Johannesburg, Transvaal, South Africa.

1847. Williams, Richard (*Life Member*), Brunswick House, Wednesbury.

1890. Williams, Thomas David, Egremont, Battle Road, Ore, near Hastings.

1881. Williams, William Freke Maxwell, 29 Great St. Helen's, London, E.C. [*Wabash, London.*]

1873. Williams, William Lawrence, 16 Victoria Street, Westminster, S.W. [*Snowdon, London.*]

1889. Williams, William Walton, Jun., 87 Elspeth Road, Lavender Hill, London, S.W.

1883. Williamson, Richard, Messrs. Richard Williamson and Son, Iron Shipbuilding Yard, Workington; and South Lodge, Cockermouth.

1870. Willman, Charles, 26 Albert Road, Middlesbrough.

1878. Wilson, Alexander, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.

1882. Wilson, Alexander Basil, Holywood, Belfast. [*Wilson, Holywood.* 201.]

1884. Wilson, James, Chief Engineer of the Daira Sanieh, Egypt: Cairo, Egypt.

1881. Wilson, John, Engineer, Great Eastern Railway, Liverpool Street Station, London, E.C. [*Wilson, Eastern, London.*]

1863. Wilson, John Charles, St. Werburgh's, Eversley Road, Bexhill-on-Sea.

1892. Wilson, John Charles Grant, Locomotive Superintendent, Manila Railway, Manila, Philippine Islands.

1879. Wilson, Joseph William, Principal of School of Practical Engineering, Crystal Palace, Sydenham, London, S.E.

1890. Wilson, Joseph William, Jun., Vice-Principal of School of Practical Engineering, Crystal Palace, Sydenham, London, S.E.

1880. Wilson, Robert, 10 St. Bride Street, London, E.C.; and 7 St. Andrew's Place, Regent's Park, London, N.W.

1883. Wilson, Robert, 13 Victoria Street, Westminster, S.W.

1890. Wilson, Robert James, 17 Kelvinhaugh Street, Glasgow.

1891. Wilson, Thomas, Morro Foundry, Iquique, Chile.

1873. Wilson, Thomas Sipling, Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Hunslet Road, Leeds.

1888. Wilson, Walter Henry, Messrs. Harland and Wolff, Belfast.

1881. Wilson, Wesley William, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.

1891. Wimshurst, James Edgar, Messrs. William Esplen, Son, and Swainston, Billiter Buildings, 22 Billiter Street, London, E.C.

1890. Winder, Charles Aston, Messrs. Winder Brothers, Royds Works, Attercliffe, Sheffield.

1886. Windsor, Edwin Wells, 1 Rue du Hameau des Brouettes, Rouen, France.

1890. Wingfield, Digby Charles, Messrs. E. Beanes and Co., Falcon Works, Hackney Wick, London, N.E.

1887. Winmill, George, Locomotive and Carriage Superintendent, Oudh and Rohilkund Railway, Lucknow, India: (or Hare Street, Romford.)

1872. Wise, William Lloyd, 46 Lincoln's Inn Fields, London, W.C. [*Lloyd Wise, London.* 2766.]

1884. Withy, Henry, Messrs. Furness Withy and Co., Middleton Ship Yard, West Hartlepool. [*Withy, West Hartlepool.* 4.]

1878. Wolfe, John Edward, General Manager, Alagoas Railway, Maceio, Brazil: (or care of Rev. Prebendary Wolfe, Arthington, Torquay.)

1878. Wolfenden, Robert, Revenue Cutter "Ling Fêng," care of Commissioner of Customs, Shanghai, China: (or 17 Dudley Street, Moss Side, Manchester.)

1888. Wolff, Gustav William, M.P., Messrs. Harland and Wolff, Belfast.

1881. Wood, Edward Malcolm, 3 Victoria Street, Westminster, S.W.

1887. Wood, Henry, Messrs. John and Edward Wood, Victoria Foundry, Bolton.

1880. Wood, John Mackworth, Engineer's Department, New River Water Works, Clerkenwell, London, E.C.

1868. Wood, Lindsay, Mining Engineer, Southhill, near Chester-le-Street.

1885. Wood, Robert Henry, 15 Bainbrigge Road, Headingley, Leeds.

1884. Wood, Sidney Prescott, Semaphore Iron Works, Newport, Melbourne, Victoria: (or care of H. W. Little, Messrs. McKenzie and Holland, Vulcan Iron Works, Worcester.)

1890. Wood, Thomas Royle, Assistant Locomotive Superintendent, Sola Works, Ferro Carril del Sud, Buenos Aires, Argentine Republic.

1890. Wood, William, 5 Grange Court Road, Stoke Newington, London, N.

1882. Woodall, Corbet, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1894. Woods, William Henry, Messrs. Hamilton Woods and Co., Liver Foundry and Engine Works, Ordsal Lane, Salford, Manchester. [*Sluice, Manchester.* 1962.]

1887. Worger, Douglas Fitzgerald, Assistant Engineer, Southwark and Vauxhall Water Works, Southwark Bridge Road, London, S.E.

1893. Wormald, Henry, Resident Engineer, Ackton Hall Colliery, Featherstone, near Pontefract.

1874. Worsdell, Thomas William, Stonycroft, Arnside, near Carnforth.

1894. Worsdell, Wilson, Locomotive Superintendent, North Eastern Railway, Gateshead.

1877. Worssam, Henry John, Messrs. G. J. Worssam and Son, Wenlock Road, City Road, London, N. [*Massrow, London.* 6656.]

1886. Worthington, Charles Campbell, Messrs. Henry R. Worthington, Hydraulic Works, 145 Broadway, New York, United States: (or care of the Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C.)

1888. Worthington, Edgar, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and New Home, Wellington Road, Fallowfield, Manchester.

1860. Worthington, Samuel Barton, Consulting Engineer, 33 Princess Street, Manchester; and Mill Bank, Vicarage Lane, Bowdon, R.O., near Altrincham.

1866. Wren, Henry, Messrs. Henry Wren and Co., London Road Iron Works, Manchester. [*Wrens, Manchester.*]

1881. Wrench, John Mervyn, Chief Engineer, Indian Midland Railway, Jhansi, N.W. Provinces, India.

1876. Wright, James, Messrs. Ashmore Benson Pease and Co., Stockton-on-Tees. [*Wright, Gasholder, Stockton.* 12.]

1867. Wright, John Roper, Messrs. Wright Butler and Co., Elba Steel Works, Gower Road, near Swansea.

1859. Wright, Joseph, Metropolitan Railway-Carriage and Wagon Co., Saltley Works, Birmingham; and The Gresham Club, London, E.C.

1878. Wright, William Barton, Cambridge House, Dover.

1871. Wrightson, Thomas, M.P., Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.

1891. Wroe, Joseph, 26 Park Avenue, Manchester, S.E.

1891. Wylde, Thomas, P. O. Box 1048, Johannesburg, Transvaal, South Africa.

1886. Wylie, James, Messrs. James Wylie and Co., Stonefield Engine Works, Blantyre, Glasgow. [*Wylie, Blantyre.*]

1865. Wyllie, Andrew, 1 Leicester Street, Southport.

1877. Wyvill, Frederic Christopher, 19 East Parade, Leeds.

1889. Yarrow, Alfred Fernandez, Isle of Dogs, Poplar, London, E.

1878. Yates, Henry, Brantford, Ontario, Canada.

1881. Yates, Louis Edmund Hasselts, District Locomotive and Carriage Superintendent, Eastern Bengal State Railway, Saidpore, Bengal, India: (or care of Rev. H. W. Yates, 98 Lansdowne Place, Brighton.)

1880. York, Francis Colin, Locomotive Superintendent, Buenos Aires and Pacific Railway, Junin, Buenos Aires, Argentine Republic: (or care of W. Hannay, 18 Portland Street, Leamington.)

1889. Young, David, 11 and 12 Southampton Buildings, London, W.C.

1879. Young, George Scholey, Engineer, Thames Iron Works, Orchard Yard, Blackwall, London, E.

1874. Young, James, Managing Engineer, Lambton Engine and Iron Works, Fence Houses.

1879. Young, James, Salroyd, 21 Cambalt Road, Putney, London, S.W.

1892. Young, Robert, Superintending Engineer, Penang Steam Tramways, Penang, Straits Settlements.

1887. Young, William Andrew, Messrs. Lobnitz and Co., Renfrew, near Paisley [*Lobnitz, Renfrew.* 57, *Paisley.*]; and Millburn House, Renfrew, near Paisley.

1881. Younger, Robert, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

ASSOCIATE MEMBERS.

1894. Almond, Michael, District Locomotive Inspector, Cape Government Railways, Queenstown, South Africa: (or care of Robert Almond, 21 Hawthorn Road, South Gosforth, Newcastle-on-Tyne.)

1894. Ambler, Frank, Assistant Resident Engineer, Alagoas Railway, Maceio, Brazil.

1894. Anderson, Tom Scott, 59 Wilkinson Street, Sheffield.

1894. Armstrong, William Henry, Water Works, Wellington Square, Calcutta, India.

1894. Aveline, William Rebotier, Messrs. George Gahagan and Co., Bellasis Road, Byculla, Bombay, India.

1888. Barker, Eric Gordon, Locomotive Superintendent, Wirral Railway, Dock Station, Birkenhead; and Guyse House, Oxton, R.O., near Birkenhead.

1893. Barker, Frederic William, 33A Hammersmith Broadway, London, W. [*Barker, Broadway, Hammersmith.*]; and 28 Prebend Gardens, Chiswick, London, W.

1894. Baron, Francis Edward, Hampton Wick Iron Works, Kingston-on-Thames. [*Baron, Hampton Wick.*]

1893. Beazley, Ernest, 3 Carlton Mansions, Coldharbour Lane, Brixton, London, S.W.

1893. Bishop, Henry, 38 Gresham Street, Lincoln.

1892. Bromly, Alfred Hammond, Choukpazat Gold Mine, Nankan Post Office, viâ Wuntho, Upper Burma: (or Llanuwchllyn, near Bala, Merionethshire).

1893. Burden, Alfred George, Messrs. Tangyes, P. O. Box 818, Johannesburg, Transvaal, South Africa: (or care of George N. Burden, Oakfield, Teignmouth.)

1894. Clark, James Lester, Messrs. Clark and Aiton, 102 Fenchurch Street, London, E.C. [*Channeled, London.*]

1894. Collis, Alfred Edward, Lincoln Science School, Monk's Road, Lincoln.

1893. Corkhill, William, General Superintendent, Asiatic Steam Navigation Co., 6 Lyons, Calcutta, India.

1894. Coventry, Theodore, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester. [*Gresley, Manchester.* 564.]

1893. Cowell, John Ray, P.O. Box 2141, Johannesburg, Transvaal, South Africa.

1887. Crosland, Delevante William, 22 Royal Crescent, Kensington, London, W.

1894. Dadina, Hormuz Minocher, Consulting Engineer, Khetwady, Bombay, India.

1894. Davey, Edward Ernest George, 49 Great Marylebone Street, London, W.

1890. Davidson, Albert, Messrs. Hattersley and Davidson, Arundel Engineering Works, 14 and 16 Arundel Street, Sheffield.

1890. Day, Arthur Godfrey, Director of Studies, Science Art and Technical Schools, Bath.

1894. Dickinson, Harold, Central Electric Lighting Station, Yorkshire House to House Electricity Co., Whitehall Road, Leeds. [*Electricity, Leeds.* 1013.]

1894. Dunolly, Alan, Albion Works, Hyde, near Manchester.

1894. Eastmead, Frederic James, 39 Victoria Street, Westminster, S.W.

1892. Edgcome, James Edmund, Resident Engineer, Electric Light Station, Kingston-on-Thames.

1893. Edmondson, Alfred Richard, Central Board School, Deansgate, Manchester.

1894. Ewen, John Taylor, 14 Tremadoc Road, Clapham, London, S.W.

1894. Fendick, Walter, Gas Works, Hemel Hempstead.

1894. Finlayson, David, Larbert, Stirlingshire.

1894. Fitz-Gerald, John Frederick Gerald, 2 Kempton Villas, Stain Hill Park, Hampton, Middlesex.

1892. Fletcher, Joseph Ernst, Messrs. Thomas Firth and Sons, Norfolk Steel Works, Sheffield.

1894. Graham, Maurice, Olive House, Central Hill, Upper Norwood, London, S.E.

1893. Gritton, Joseph, 97 Highbury Quadrant, London, N.

1894. Hadengue, Charles Benjamin, Messrs. Carew and Co., Rosa Sugar Works, Rosa, North Western Provinces, India.

1894. Hall, Robert Frederick, Cycle Components Manufacturing Co., Sampson Road North, Sparkbrook, Birmingham. [*Decimal, Sparkbrook.* 606.]

1894. Hardy, William, Woodview, Bessbrook, County Armagh, Ireland.

1894. Harris, Herbert Nelson, St. Michael's Foundry, Bridport.

1894. Hawley, Cecil Edward, Mansion House Chambers, 11 Queen Victoria Street, London, E.C.

1894. Henderson, Arthur James, 2 Lombard Court, Gracechurch Street, London, E.C.

1893. Human, Edwin, Superintendent, Technical School, Colombo, Ceylon; and Halifax House, Robinson Street, Cinnamon Gardens, Colombo, Ceylon.

1894. Hyde, George Herbert, Managing Engineer, Colombo Commercial Co., Colombo, Ceylon.

1893. Jenkin, Charles James, Trewirgie, Redruth.

1893. Kershaw, Thomas, Technical School, Huddersfield.

1894. Kerslake, Walter Edmund, 34 Great George Street, Liverpool.

1893. Kirk, Percy Roebuck, 2 Forest View, Epping New Road, Buckhurst Hill, S.O., Essex.

1893. Lea, Arthur Henry, Messrs. Lea Sons and Co., Pengwerne Works, Shrewsbury.

1894. Mansfield, Edwin Albert, 1 Aldermanbury Buildings, London, E.C.
1893. Manton, Arthur Woodroffe, New Docks 14 and 15, H. M. Dockyard, Portsmouth.
1894. McGeorge, James, Bombay Burmah Trading Corporation, Rangoon, British Burmah, India.
1894. Mills, Arthur Edwin, The Chestnuts, Wick, near Bath.
1893. Mitchell, James Frederick Bruce, Messrs. J. F. B. Mitchell and Co., Mazagon Iron Works, Bombay, India.
1894. Monckton, Charles John, Superintendent Engineer, Messrs. T. H. Saunders and Co., Darenth Paper Mill, near Dartford.
1893. Mountain, Benjamin, 82 Ravenswood Terrace, Hyde Park, Leeds.
1893. Moylan, William Morgan, care of Messrs. Grindlay and Co., Calcutta, India.
1894. Murphy, Edward Owen, R.N.R., Chief Engineer, R.M.S. "Empress of Japan," Vancouver, British Columbia.
1889. Nasmith, Joseph, 61 Barton Arcade, Manchester.
1894. North, Horace, St. George's Engineering Works, Trafalgar Street, Brighton.
1893. Paterson, Robert Mair, Manager, Thames Cycle Co., Barnes, London, S.W.
1893. Pertwee, Herbert Arthur, Messrs. Elliott's Metal Co., Pembrey Copper Works, Burry Port, R.S.O., Carmarthenshire.
1894. Poppleton, Clement Francis, Messrs. Aveling and Porter, Rochester; and 8 Clifden Road, Clapton, London, N.E.
1894. Raleigh, Charles, P.O. Box 1905, Johannesburg, Transvaal, South Africa.
1894. Ramsbottom, John Goodfellow, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.
1893. Richey, William Frederick Albert, Messrs. Chance Brothers and Co., Lighthouse Works, near Birmingham.
1893. Roberts, Charles Thomas, 19 and 23 Chorlton Chambers, Johannesburg, Transvaal, South Africa. [*Roberts, Engineer, Johannesburg.*]
1894. Rossiter, James Thomas, Tynwald, Grove Park Road, Chiswick, London, W.
1894. Rowe, Daniel, Engineer, Ferreira Gold Mining Co., Johannesburg, Transvaal, South Africa: (or care of Mrs. Rowe, Trevingey Terrace, Redruth.)
1894. Salis, Henry Rodolph de, Fairacres, Oxford.
1893. Schloesser, Robert, P. O. Box 209, Johannesburg, Transvaal, South Africa: (or care of Adolf Schloesser, 185 Sutherland Avenue, London, W.)
1893. Segundo, Edward Carstensen de, 28 Victoria Street, Westminster, S.W.
1894. Smith, William Arthur, Midland Arches, Northampton; and 18 Albion Place, Northampton. [*Machinery, Northampton.*]

1893. Stockton, Joseph Sadler, Stopper, Box, and Stamp Works, Icknield Street, Birmingham.

1894. Stone, Sidney, Great Eastern Railway, Stratford Works, London, E.

1894. Sutton, Hugh Reginald, Messrs. Mackies, Berks Iron Works, Caversham Road, Reading. [*Mackies, Reading.* 86.]

1893. Takatsuji, Narazo, Superintending Engineer, Calico Weaving Mill, Osaka, Japan.

1893. Talbot, Frederick William, Assistant Engineer, Lambeth Water Works, Surbiton, Surrey; and 7 Prospect Place, Long Ditton, Surbiton, Surrey.

1894. Taylor, William, Messrs. Taylor, Taylor, and Hobson, Slate Street Works, Leicester. [*Lenses, Leicester.* 134.]

1893. Tenney, Dennis, 53 Trinity Street, Hull.

1893. Thomasson, Lucas, Cotlands, London Colney, St. Albans.

1894. Thomson, Henry, Engineer, Cawnpore Woollen Mills, Cawnpore, India.

1893. Thomson, James Watson, Robert Gordon's College, Aberdeen.

1894. Thorpe, Walter Charles, Messrs. Goddard, Massey, and Warner, Traffic Street, Nottingham.

1893. Tomes, William Jameson, Locomotive Department, London and South Western Railway, Nine Elms, London, S.W.

1893. Tomlinson, William Augustus, P.O. Box 1978, Johannesburg, Transvaal, South Africa: (or care of John Tomlinson, Birthorpe Manor, Billingborough, near Folkingham.)

1893. Turner, Henry Arthur, care of Arthur Koppel, 96 Leadenhall Street, London, E.C.

1893. Walker, Charles Christopher, Messrs. Walker, Eaton and Co., Wicker Iron Works, Sheffield. [*Founder, Sheffield.* 376.]

1894. Wasdell, Thomas, Jun., Water Works Road, Edgbaston, Birmingham.

1893. Watson, George, The Glenfield Engineering Works, Kilmarnock.

1893. Wells, Sidney Herbert, Principal, Battersea Polytechnic Institute, Battersea, London, S.W.

1893. Wilkins, George Cornelius, Sir W. G. Armstrong Mitchell and Co., Elswick Ordnance Works, Newcastle-on-Tyne.

1889. Willis, Edward Turnley, Hockley Hall and Whateley Colliery, Tamworth.

1890. Winmill, Hallett, P.O. Box 1161, Johannesburg, Transvaal, South Africa: (or care of C. C. Winmill, 14 Ham Frith Road, Stratford, London, E.)

1894. Young, Smelter Joseph, Messrs. E. Bennis and Co., Lancashire Stoker Works, Deansgate Foundry, Bolton.

ASSOCIATES.

1880. Allen, William Edgar, Imperial Steel Works, Cross George Street, Sheffield.

1881. Barcroft, Henry, Bessbrook Spinning Works, County Armagh, Ireland; and The Glen, Newry, Ireland.

1889. Barr, John, The Glenfield Engineering Works, Kilmarnock.

1886. Bennison, William Clyburn, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield; and 38 Wellington Street, Higher Broughton, Manchester.

1890. Birch, John Grant, 10 and 11 Queen Street Place, London, E.C.

1892. Bowman, Frederic Hungerford, D.Sc., F.R.S.E., Mayfield, Knutsford.

1888. Brown, Harold, Messrs. Linklater, Hackwood, Addison and Brown, 2 Bond Court, Walbrook, London, E.C.

1890. Burt, John Mowlem, Messrs. John Mowlem and Co., 19 Grosvenor Road, Pimlico, London, S.W.

1891. Carter, Frederick Heathcote, 9 Oxford Street, Manchester. [*Girder, Manchester.*]

1889. Castle, Frederick George, The People's Palace Technical Schools, Mile End Road, London, E.

1889. Chamberlain, John George, Messrs. Joseph Wright and Co., Neptune Forge, Tipton.

1888. Chrimes, Charles Edward, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1890. Chubb, Richard, Messrs. Gillison and Chadwick, 10 Tower Buildings, Liverpool.

1893. Clarke, Edward Fuhrmann, Curzon Chambers, Paradise Street, Birmingham; and Four Oaks, Sutton Coldfield, near Birmingham.

1879. Clowes, Edward Arnott, Messrs. William Clowes and Sons, Duke Street, Stamford Street, London, S.E. [*Clowes, London.* 4558.]

1892. Cooper, Thomas Lancelot Reed, 79 Western Road, Hove, near Brighton.

1892. Cryer, Arthur, University College, Cardiff.

1893. Darlington, John, Engine and Boiler Insurance Co., Manchester, and 3 Marlborough Gardens, Ealing, London, W.

1892. Davis, George Brown, Palace Wharf, Stangate, London, S.E.; and Cambridge House, 242 South Lambeth Road, London, S.W.

1892. Fauvel, Charles James, 15 George Street, Mansion House, London, E.C. [*Charlock, London.*]

1891. Foster, George, Hecla Foundry Steel Works, Sheffield; and Lyme Villa, Rotherham.

1889. Golby, Frederick William, 36 Chancery Lane, London, W.C.
1889. Götz, Carl Johann Wilhelm, Messrs. John M. Sumner and Co., 2 Brazennose Street, Manchester.
1889. Gregory, George Francis, Boarzell, Hawkhurst.
1894. Hayes, John, Messrs. W. P. Thompson and Co., 11 Burlington Chambers, New Street, Birmingham.
1887. Hind, Enoch, Edgar Rise, Nottingham.
1891. Jackman, Joseph, Persberg Steel Works, Pothouse Road, Attercliffe, Sheffield. [*Persberg, Sheffield.* 94.]
1884. Jackson, Edward, Midland Railway-Carriage and Wagon Works, Birmingham. [*Wagon, Birmingham.*]
1882. Jackson, William, Kingston Cotton Mill, Hull. [*Cotton, Hull.*]
1891. Jennings, George Henry, Stangate, Lambeth, London, S.E. [*Jennings, London.* 4680.]
1890. Jennings, Sidney, Stangate, Lambeth, London, S.E. [*Jennings, London.* 4680.]
1881. Lowood, John Grayson, Gannister Works, Attercliffe Road, Sheffield. [*Lowood, Sheffield.* 131.]
1886. Mackenzie, Keith Ronald, Gillotts, Henley-on-Thames.
1868. Matthews, Thomas Bright, Messrs. Turton Brothers and Matthews, Phœnix Steel Works, Sheffield. [*Matthews, Sheffield.*]
1890. McGillivray, William, Messrs. Austin McGillivray and Co., Falcon Works, Sheffield. [*Austin, Sheffield.*]
1889. McKinnel, William, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.
1891. McMeekin, Adam, Cogry Flax Spinning Mills, Doagh R.S.O., Co. Antrim, Ireland.
1890. Meggitt, Samuel Newton, Messrs. Ibbotson Brothers and Co., Globe Steel Works, Sheffield.
1889. Miles, William Henry, 23 Barnato Buildings, and P.O Box 1860, Johannesburg, Transvaal, South Africa.
1891. Monie, Hugh, Jun., Textile Section, Victoria Jubilee Technical Institute, Byculla, Bombay, India: (or care of Hugh Monie, Springfield, Belfast.)
1892. Morley, John, Sanitary Engineering Works, Palace Wharf, Stangate, London, S.E.
1887. Neville, Edward Hermann, 18 Calle Alcala, Madrid, Spain.
1886. Newton, Henry Edward, 6 Bream's Buildings, Chancery Lane, London, E.C.
1874. Paget, Berkeley, Low Moor Iron Office, 2 Laurence Pountney Hill, Cannon Street, London, E.C. [*Gryphon, London.*]
1886. Peacock, William J. P., Wells Street, Oxford Street, London, W.; and 41 St. James' Street, London, S.W.
1888. Peake, Robert Cecil, Cumberland House, Redbourn, near St. Albans.

1887. Peech, Henry, Phœnix Bessemer Steel Works, near Sheffield; and 49 Victoria Street, Westminster, S.W.

1887. Peech, William Henry, Phœnix Bessemer Steel Works, near Sheffield; and Fernbank, Roehampton Park, London, S.W.

1894. Peters, Lindsley Byron, Messrs. G. D. Peters and Co., Moorgate Works, Moorfields, London, E.C. [*Peters, London.*]

1884. Phillips, Richard Morgan, 21 to 24 State Street, New York, United States. [*Sarita, New York.*]

1891. Pirrie, John Barbour, Barn Flax Spinning Mills, Carrickfergus, Co. Antrim, Ireland.

1891. Plant, George, Moseley Road School, Birmingham.

1891. Rankin, Thomas Thomson, Principal, Coatbridge Technical School and West of Scotland Mining College, Coatbridge.

1886. Raven, Henry Baldwin, Messrs. Hare and Co., Temple Chambers, Temple Avenue, London, E.C.

1892. Reed, Ernest Charles, Riverside Mills, Dartford.

1891. Rochfort, Bertram, Caixa 932, Rio de Janeiro, Brazil.

1891. Rowcliffe, William Charles, 1 Bedford Row, London, W.C.

1888. Rowell, John Henry, New Brewery, High Street, Gateshead.

1890. Schofield, John William, Messrs. Gregory and Bramall, Soho Steel and File Works, Sheffield.

1887. Scott, Walter, Victoria Chambers, Grainger Street West, Newcastle-on-Tyne. [*Contractor, Newcastle-on-Tyne.*]

1893. Simpson, Edward Percy, Messrs. Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.

1891. Spencer, Francis Henry, P.O. Box 1338, Johannesburg, Transvaal, South Africa.

1892. Stead, John Edward, 5 Zetland Road, Middlesbrough.

1886. Stumore, Frederick, 34 Leadenhall Street, London, E.C.

1890. Taylor, John, 99 and 101 Fonthill Road, Finsbury Park, London, N.; and Stockport.

1887. Tozer, Edward Sanderson, Phœnix Bessemer Steel Works, near Sheffield.

1893. Wadham, Arthur, 171 Queen Victoria Street, London, E.C. [*Wadham, London.*]

1878. Watson, Joseph, Patent Office, 25 Southampton Buildings, London, W.C.

1892. Whitehead, Richard David, Municipal Technical College, Green Hill, Derby.

1892. Widdows, Francis R., Messrs. Colman's Mustard Mills, Carrow Works, Norwich.

1883. Williamson, Robert S., Cannock and Rugeley Collieries, Hednesford, near Stafford.

1891. Wiseman, Edmund, Cheapside and John Street, Luton. [*Wiseman, Luton.*

GRADUATES.

1892. Adams, Sidney Rickman, care of Henry Adams, 3 Colville Square, Bayswater, London, W.

1885. Addis, Frederick Henry, District Locomotive Superintendent, Rajputana-Malwa Railway, Sirsa, Punjaub, India: (or care of Messrs. Grindlay and Co., 55 Parliament Street, London, S.W.)

1893. Alderson, Charles Albert Heselton, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln; and 13 Cheviot Street, Lincoln.

1890. Alderson, George Alexander, Norland House, Ramleh, Alexandria, Egypt.

1894. Ambrose, Sewell Powis, 56 Vyse Street, Hockley, Birmingham; and Swaffham Prior, Cambridgeshire.

1882. Anderson, William, Locomotive Department, North Eastern Railway, Gateshead.

1878. Appleby, Charles Tallis, St. George's Iron Works, Manchester.

1889. Ashford, John, Municipal Technical School, Midland Institute, Paradise Street, Birmingham.

1890. Aubin, Percy Adrian, 29 St. James' Street, St. Helier's, Jersey.

1894. Aylesbury, Thomas Antram, The Elms, Carshalton Road, Sutton, Surrey.

1888. Bailey, Wilfred Daniel, India-rubber Gutta-percha and Telegraph Works, Casilla de Correo 1212, Buenos Aires, Argentine Republic.

1894. Barber, Edward Whitley, 6 Victoria Station Approach, Manchester.

1889. Barrow, Arthur Robert Maclean, care of Messrs. William Watson and Co., 28 Apollo Street, Bombay, India: (or care of Mrs. Barrow, Holly Grove, Fittleworth, Pulborough.)

1893. Bealey, Harold Edward, Messrs. Bolckow Vaughan and Co., Cleveland Iron and Steel Works, South Bank, R.S.O., Yorkshire; and The Vicarage, Middlesbrough.

1893. Bedbrook, James Albert Harvey, Haresfield, Blenkarne Road, Wandsworth Common, London, S.W.

1888. Bell, Alexander Dirom, 182 Great Clowes Street, Broughton, Manchester.

1884. Bell, Robert Arthur, Assistant Locomotive and Carriage Superintendent, South Indian Railway, Cuddalore (New Town), Madras, India: (or care of Mrs. Bell, 30 Brompton Crescent, London, S.W.)

1890. Bell, William Thomas, Sunny Mount, Yarborough Road, Lincoln.

1888. Bradley, Arthur Ashworth, Princess Estate and Gold Mining Co., Roodepoort, near Johannesburg, Transvaal, South Africa: (or care of Rev. Gilbert Bradley, St. Edmund's Vicarage, Dudley, Worcestershire.)

1887. Bremner, Bruce Laing, 21 Langworthy Road, Manchester: (or Streatham House, Canaan Lane, Edinburgh.)

1894. Britten, Thomas, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1890. Brousson, Robert Percy, City and Guilds of London Central Institution, Exhibition Road, London, S.W.

1889. Brown, Arthur Selwyn, Hayes Street, Neutral Bay, Sydney, New South Wales.

1893. Bruce, Robert Arthur, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton.

1880. Buckle, William Harry Ray, 11 Billiter Buildings, 49 Leadenhall Street, London, E.C.

1892. Bulwer, Ernest Henry Earle, Messrs. George Fletcher and Co., Poplar Iron Works, King Street, Poplar, London, E.

1890. Burne, Edward Lancaster, Messrs. Weyman and Hitchcock, Church Acre Iron Works, Guildford.

1893. Burtt, George Frank, Locomotive Department, London Brighton and South Coast Railway, Brighton; and 37 Bonchurch Road, Hassocks, R.S O., Sussex.

1891. Butcher, Walter Edward, Messrs. Weyman and Hitchcock, Trusty Engine Works, Cheltenham.

1891. Buttenshaw, George Eskholme, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1889. Calastremé, John Carlos, care of Robert Weatherburn, 93 Highgate Road, London, N.W.

1891. Caswell, Charles Henry, Naval Construction and Armaments Works, Barrow-in-Furness.

1894. Cater, John McIlvaine, Southdown, The Downs, Wimbledon.

1889. Challen, Walter Bernard, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham.

1890. Chatwood, Arthur Brunel, Chatwood's Safe and Lock Co., 76 Newgate Street, London, E.C.

1891. Church, Harry, Ingeniero, para la Colonia San Gustavo, La Paz, Entre Rios, South America: (or care of George Church, Willington, Bedford.)

1890. Cleeves, John Frederick, Messrs. E. A. Cleeves and Co., 3 Mileage Wharf, Westbourne Park Road, London, W.

1892. Cleverly, William Bartholomew, Messrs. John Brown and Co., Perseverance Works, 6 Bow Common Lane, London, E.

1885. Clift, Leslie Everitt, 1 Holborn Place, High Holborn, London, W.C.

1892. Collingridge, Harvey, Messrs. S. Pearson and Son, Blackwall Tunnel Works, East Greenwich, London, S.E.; and Ingleborough, The Ridgway, Enfield.

1889. Cook, George Norcliffe, Messrs. Thomas Firth and Sons, Norfolk Works, Sheffield.

1888. Cox, Herbert Henry, Hillside, Falmouth.

1891. Cutler, Samuel, Jun., Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E.

1894. Darwood, John William, Ahloue, Rangoon, Burma.

1884. Dixon, John, Eastwood Villa, Lytham, near Preston, Lancashire.

1893. Douglas, William Saunders, Consett Iron Works, Consett, R.S.O., County Durham; and 60 Durham Road, Blackhill, R.S.O., County Durham.

1891. Douglass, Alfred Edwards, South Staffordshire Water Works, Paradise Street, Birmingham.

1891. Duncan, Martin Gordon, Lexden, 63 Elmfield Road, Upper Tooting, London, S.W.

1891. Edwards, Herbert Francis, Messrs. Forster Brown and Rees, Guild Hall Chambers, Cardiff.

1885. Edwards, Walter Cleeve, care of the Venerable Archdeacon Edwards, Dunedin, New Zealand.

1893. Fox, Frederick Joseph, 49 Farquhar Road, Upper Norwood, London, S.E.

1894. Fry, Henry Walter, Locomotive Department, London Brighton and South Coast Railway, Brighton; and Leydenburgh, Port Hall Street, Brighton.

1890. Garrett, Frank, Jun., Messrs. Richard Garrett and Sons, Leiston Works, Leiston, R.S.O., Suffolk.

1891. Gillatt, Thomas Stanley, care of A. C. Chamberlin, Kelburne Estate, Haputalia, Colombo, Ceylon: (or care of Mrs. Gillatt, Broomknowe, Row, Dumbartonshire.

1891. Gregory, Henry Hodges Mogg, Messrs. Sanders and Co., Rivington Works, Rivington Street, Great Eastern Street, London, E.C.

1894. Halsey, Charles Turner, Womersley House, Dickenson Road, Hornsey, London, N.

1890. Hatton, Thomas Reginald, Grosvenor House, Gloucester Road, Ross, Herefordshire.

1889. Hayward, Robert Francis, Salt Lake and Ogden Gas and Electric Light Co., Salt Lake City, Utah, United States.

1877. Heaton, Arthur, Messrs. Heaton and Dugard, Metal and Wire Works, Shadwell Street, Birmingham. [*Heagard, Birmingham.*]

1874. Hedley, Thomas, Room 20, Sherlock Building, Portland, Oregon, United States.

1893. Heinrich, Herbert Rodolph, Melbourne House, Worple Road, Wimbledon.

1894. Hodges, Frank William, Messrs. Alexander Wilson and Co., Vauxhall Iron Works, Wandsworth Road, London, S.W.; and Tullgarn, 37 Cromwell Road, West Brighton, Brighton.

1891. Hodgson, William James, Central Chemical Co., 182 London Road, Nottingham.

1887. Hogg, William, Craigmore, Blackrock, Dublin.

1894. Hollingsworth, Edward Massey, Corporation Gas Works, Warrington Old Road, St. Helen's, Lancashire.

1884. Holt, Follett, Ferro Carril Buenos Aires y Rosario, La Banda, Argentine Republic: (or care of Robert Hallett Holt, Land Registry, Staple Inn, Holborn, London, W.C.)

1889. Hosgood, Thomas Watkin, Sketty, near Swansea.

1891. Hosgood, Walter James, Locomotive Department, Barry Dock and Railways, Barry, near Cardiff.

1889. Hosken, Arthur Fayrer, Locomotive Department, Caledonian Railway, St. Rollox, Glasgow.

1889. Howard, Geoffrey, Britannia Iron Works, Bedford.

1883. Howard, Harry James, Messrs. Colman's Mustard Mills, Carrow Works, Norwich.

1891. Hughes, Edward Sinclair Bremner, Madgefield, Helensburgh.

1894. Ironside, William Allan, Messrs. Ironside, Gyles and Co., 1 Gresham Buildings, Guildhall, London, E.C.

1894. Jamieson, James Lindsay Auldjo-, Messrs. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1894. Johnson, Walter Wroe, Castleton Foundry and Engineering Works, Armley Road, Leeds.

1890. Jones, Arthur Dansey, Locomotive Department, Lancashire and Yorkshire Railway, Wakefield; and 1 Hanover Place, Doncaster Road, Wakefield.

1891. Jordan, Frederic William, 42 Wells Street, Mortimer Street, Cavendish Square, London, W.

1889. Joy, Basil Humbert, 17 Victoria Street, Westminster, S.W.; and Manor Road House, Beckenham.

1883. Lander, Philip Vincent, Lyndhurst, Hampton Wick, R.O., Kingston-on-Thames: (or care of W. W. Lander, Imperial Ottoman Bank, 26 Throgmorton Street, London, E.C.)

1894. Larmuth, William Oliver, Messrs. Thomas Larmuth and Co., Todleben Iron Works, Unwin Street, Cross Lane, Salford, Manchester; and 48 Fitzwarren Street, Pendleton, Manchester.

1881. Lawson, James Ibbs, Resident Engineer, New Zealand Railways, Wanganui, New Zealand.

1886. Lewis, William Thomas, Jun., Engineer's Office, Bute Docks, Cardiff; and 89 Albany Road, Cardiff.

1894. Lloyd, Thomas Zachary, Messrs. Nettlefolds, Smethwick, Birmingham; and Arcley Hall, Stourport.

1881. Macdonald, Ranald Mackintosh, Messrs. Booth Macdonald and Co., Carlyle Engineering and Implement Works, Christchurch, New Zealand; and P.O. Box 267, Christchurch, New Zealand.

1883. Mackenzie, Thomas Brown, Messrs. J. Copeland and Co., Pulteney Street Engine Works, Glasgow; and 342 Duke Street, Glasgow.

1893. Mackesy, Walter, 17 Campden House Road, Kensington, London, W.

1894. Mansfield, Alfred, Messrs. P. Orr and Sons, Madras, India.

1894. Mansfield, Walter, Messrs. Edwin Mansfield and Sons, 140 Great Clowes Street, Broughton, Manchester. [*Gaslight, Manchester.*]

1868. Mappin, Frank, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.

1892. Marks, Alfred Pally, 155 Adelaide Road, London, N.W.

1889. Marshall, Frank Theodore, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1888. Marten, Hubert Bindon, Contractor's Office, Manchester, Sheffield and Lincolnshire Railway, Leicester; and Pedmore, Stourbridge.

1886. Mattos, Alvaro Gomes de, 98 Rua da Sande, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1892. Miles, Frederick Hudson, Locomotive Department, London and South Western Railway, Nine Elms, London, S.W.

1891. Mills, Matthew William, Moss Foundry, Heywood, near Manchester.

1867. Mitchell, John, Heathercliffe Lodge, Penistone.

1894. Moon, Edgar Rupert, 9 Gloucester Terrace, Swindon.

1868. Moor, William, Ocean House, Hartlepool.

1893. Morgan, George Herbert, University College, Liverpool.

1892. Murray, David James, 62 Lloyd Street, Greenheys, Manchester.

1878. Newall, John Walker, Suffolk House, Laurence Pountney Hill, London, E.C.

1883. O'Connor, John Frederick, 16 and 18 Exchange Place, New York, United States.

1883. Osborn, William Fawcett, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1892. Osmond, Frederick John, The Tower, Bagot Street, Birmingham. [*Osmond, Birmingham.* 550.]

1881. Oswell, William St. John, Messrs. Oswell and Henry, Calle Defensa 117 al 119, Buenos Aires, Argentine Republic.

1883. Palchoudhuri, Bipradas, Moheshgunj Factory, Krishnugher, Bengal.

1887. Paterson, John Edward, Chief Mechanical Engineer's Office, New South Wales Government Railways, Wilson Street, Eveleigh, Sydney, New South Wales.

1892. Payton, Frank John, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1894. Petter, Percival Waddams, The Foundry, Yeovil.

1890. Philipson, John, Jun., Messrs. Atkinson and Philipson, 27 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]

1884. Philipson, William, Messrs. Atkinson and Philipson, 27 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]

1890. Powell, Frederick, York House, Malvern Link, Malvern.

1892. Power, Arthur Cyril, 17 Fordwych Road, Brondesbury, London, N.W.

1893. Price, William Frederick, Corporation Electricity Works, Cotton Street, Aberdeen.

1887. Price-Williams, John Morgan, 28 Ormiston Road, Westcombe Park, Blackheath, London, S.E.

1892. Ransom, Herbert Byrom, Messrs. Manlove Alliott and Co., 57 Gracechurch Street, London, E.C.

1894. Readhead, Robert, Jun., Messrs. John Readhead and Sons, West Docks, South Shields.

1892. Redfern, Charles George, 122 Bethune Road, Stamford Hill, London, N.

1884. Reynolds, Thomas Blair, 28 Victoria Street, Westminster, S.W.

1894. Richmond, William Frederick, Great Brunswick Ironworks and Foundry Co., Sir John Rogerson's Quay, Dublin; and 261 Norwood Road, Herne Hill, London, S.E.

1892. Ridley, James Cartmell, Jun., 3 Summerhill Grove, Newcastle-on-Tyne.

1889. Roope, Walter, Stisted, Badulla, Ceylon: (or care of Mrs. Roope, Hangerfield, Witley, Godalming.)

1884. Roux, Paul Louis, 54 Boulevard du Temple, Paris.

1888. Rümmele, Alfredo, 17 Via Principe Umberto, Milan, Italy.

1894. Russell, William Colin, Gwalia Tin-Plate Works, Briton Ferry; and Hafod, Swansea.

1890. Sanders, Percy Henry, Messrs. H. G. Sanders and Son, Victoria Works, Victoria Gardens, Notting Hill Gate, London, W.

1890. Saxelby, Herbert Raffaelle, 7 and 8 Ironmonger Lane, Cheapside, London, E.C.

1892. Scarfe, George Norman, care of George Scarfe, Gawler Place, Adelaide, South Australia.

1881. Scott, Ernest, Messrs. Ernest Scott and Mountain, Close Works, Newcastle-on-Tyne. [*Esco, Newcastle-on-Tyne.* 432.]

1892. Seymour, William Frederick Earl, Engineer's Office, Great Western Railway, Swindon.

1893. Sharpley, George Ruston, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln.

1892. Shepherd, James Horace, Great Western Railway, Swindon.

1886. Silcock, Charles Whitbread, 12 Arlington Road, Surbiton.

1887. Simkins, Charles Wickens, Jun., Amguri Tea Estate, Amguri Post Office, Sibsagar, Assam, India: (or care of Charles W. Simkins, The Lodge, Lowdham, near Nottingham.)

1893. Simon, Ingo, 20 Mount Street, Manchester.

1894. Simpson, Lightly Stapleton, Trinity College, Cambridge; and 16 Kent Terrace, Regent's Park, London, N.W.

1894. Skinner, Russell Foster, 57 Lupus Street, Pimlico, London, S.W.; and 6 Cambridge Road, Brighton.

1891. Smith, Joseph Philip Grace, Polytechnic School of Engineering, 309 Regent Street, London, W.

1891. Snell, John Francis Cleverton, St. Pancras Electricity and Public Lighting Department, 47 Stanhope Street, London, N.W.; and 79 St. Augustine's Road, Camden Square, London, N.W.

1892. Stokes, Frank Torrens, P.O. Box 1355, Johannesburg, Transvaal, South Africa.

1894. Suffield, Frank Wilson, Messrs. Samuel Fisher and Co., Nile Foundry, Nile Street, Birmingham.

1887. Tabor, Edward Henry, Blackwall Tunnel Works, East Greenwich, London, S.E

1885. Tangye, John Henry, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.

1884. Taylor, Joseph, 24 Hawthorn Grove, Heaton Moor, near Stockport.

1884. Taylor, Maurice, 39 Rue de Lisbonne, Paris.

1894. Thorpe, Wilfred Bertram, Messrs. Alexander Wilson and Co., Vauxhall Iron Works, Wandsworth Road, London, S.W.; and 20 Larkhall Rise, Clapham, London, S.W.

1891. Vaizey, John Leonard, Locomotive Works, Great Eastern Railway, Stratford, London, E.; and 6 Grove Crescent, Stratford, London, E.

1892. Vezey, Albert Edward, Electrical Department, London and North Western Railway Works, Crewe.

1888. Waddington, Samuel Sugden, 35 King William Street, London Bridge, London, E.C.

1885. Wakefield, William Marsden, Messrs. John King and Co., 30 Strand Road, Calcutta, India.

1888. Waring, Henry, Engineer, Dublin Laundry Co., Milltown, near Dublin.

1892. Warton, Richard George Frank, Westerleigh, Llandaff, near Cardiff.

1886. Wesley, Joseph A., Clarke's Crank and Forge Works, Lincoln.

1880. Weymouth, Francis Marten, 27 Couthope Villas, Worple Road, Wimbledon.

1888. Whichello, Richard, Messrs. Max Nothmann and Co., Rio de Janeiro, Brazil: (or 44 Trumpington Street, Cambridge.)

1894. Whitelegg, Robert Harben, Locomotive Department, London Tilbury and Southend Railway, Plaistow, London, E.

1889. Wigham, John Cuthbert, Messrs. J. Edmundson and Co., Stafford Works, 35 Capel Street, Dublin.

1892. Williams, Arthur Edward, Messrs. Bramwell and Harris, 5 Great George Street, Westminster, S.W.

1890. Wilson, Alexander Cowan, Osgathorpe Hills, Sheffield.

1893. Wort, Walter Edward, Messrs. H. A. House and Sons, Columbine Ship Yard, East Cowes, Isle of Wight.

1887. Wrench, John Henry Kirke, 173 West Huron Street, Chicago, United States: (or care of E. M. Wrench, Park Lodge, Baslow, Chesterfield.)

1889. Wright, Howard Theophilus, 16 Great George Street, Westminster, S.W.

1890. Wright, William Carthew, General Post Office, Melbourne, Victoria: (or care of Dr. Gaskoin Wright, 253 Eccles New Road, Salford, Manchester.)

1891 Yerbury, Frederick Augustus, 17 Victoria Street, Westminster, S.W.

Institution of Mechanical Engineers.

PROCEEDINGS.

July 1894.

The Summer Meeting of the Institution was held in Manchester, commencing on Tuesday, 31st July 1894, at Ten o'clock a.m.; Professor Alexander B. W. Kennedy, LL.D., F.R.S., President, in the chair.

The President, Council, and Members were received in the Owens College by the Chairman of Council of the College, Alderman Joseph Thompson, on behalf of the Right Honourable the Lord Mayor of Manchester, Sir Anthony Marshall; and by the Right Worshipful the Mayor of Salford, Sir William H. Bailey.

Alderman Thompson said it had been the hope and the intention of the Lord Mayor of Manchester to be present on this occasion, and to give the Institution a cordial welcome to the city. Unfortunately the pressure of his numerous engagements prevented him from taking the position which he had hoped to occupy; and he had asked him to represent him. He had also the honour to appear himself in another capacity; and by virtue of the position given to him by the Council of the Owens College he was present to bid the members a cordial welcome to the building, and to its use during the meeting of the Institution. It so happened that at the same time another society was also honouring Manchester with a visit: a society which might be looked upon as the most remote from the Institution of Mechanical Engineers, and yet in one sense the two were closely linked together. The British Archæological Society was visiting Manchester, and occupying for its meeting some of the rooms in the College. A cordial welcome had already been given to that society by the Lord Mayor, who also hoped to receive the members of the

(Alderman Thompson.)

Institution of Mechanical Engineers at his Conversazione this evening in the Town Hall. In his lordship's name, as well as in his own, he desired to offer to both societies a hearty welcome. The civic honours would be given in the Town Hall, and those which related immediately to science and learning would be offered in the building in which they were now assembled. The very name of the other society recalled ancient times. Though perhaps it did not go back quite to the beginning, it dealt with those matters upon which the thoughts of men now fondly lingered, and which time had touched with its lines and hues so gently and lovingly. Most men he imagined liked to dwell in their turn upon the events of the past; and if they could not visit the interesting monuments and towns of the country, they could at least refresh their minds by reading books on the history of their forefathers. Yet however delightful and refreshing it might be to look back, it would not do for engineers to stand still in contemplation of the past. Their Institution represented the courage and activity of the present and of the future. It was like a young giant who did not know his full strength, but went forth in such strength as he was conscious of, conquering and to conquer; and it was not too much to say that all which tended to make life happy, pleasant, and useful was that which came forth from an Institution like this, whose members had bridged rivers, guided the course of streams, and given ease and safety of locomotion. Whilst the city most cordially threw open its works for their inspection and its Town Hall for their enjoyment, the College in which they were assembled also gave them welcome. It was fit that they should meet in this College, because there was here taught not only the theory but to some extent also the practice of mechanical engineering. And none knew better than themselves that engineering was associated with various forms of training. The engineer must be a mathematician; and in the College were taught both applied mathematics and pure mathematics. An engineer was also well aware that he must be somewhat of a chemist, and must know something of the composition and mixture of metals. In Owens College chemistry was taught, and the lecture theatre in which they were assembled had witnessed the teaching of Roscoe

and Schorlemmer, Thorpe and others; and was now occupied for that purpose by Professors Dixon and Perkin. Then again engineering was allied closely with electricity, in which the College had the benefit of the teaching of Professor Schuster, whose classes were crowded. The Institution whose members he was addressing had to embrace more or less different forms of thought and of culture; and in this building it was the business of the professors to the best of their ability to train young men in those various branches of knowledge. In the name of the Lord Mayor and the Corporation of Manchester, and of the Council of the Owens College, he offered the Institution a cordial welcome, first to the city with its buildings and works, and then to the Owens College.

The MAYOR OF SALFORD, Sir William H. Bailey, said that, although they greatly regretted the absence of the Lord Mayor of Manchester to welcome the Institution, the city of Manchester had been well represented by Alderman Thompson: not only the intellect of Manchester and its scholarly ability, but the magnificent hospitality of the city had been well represented in the excellent speech to which they had listened. As the Mayor of Salford, the borough across the stream, it was also his own pleasant duty to welcome the members of the Institution to the district. It would be difficult indeed for the members of a mechanical engineering society to come to any part of England which possessed more evidences of mechanical engineering than this particular district. Indeed if they looked at the historical development of mechanical tools, or even of the modern locomotive, they found that the inventors of this district had had a remarkable influence upon engineering industries and inventions. That was the case even with the steamboat. Fulton, before he went to Paris, had made an experiment upon the Bridgewater Canal; and engines with a boiler of about 4 lbs. pressure were made in Salford in 1795. After trying his model in Salford and making his experiments, he went to the Seine; and it was remarkable that Napoleon Bonaparte had then said, "Citizen Fulton has placed before us an invention which in my opinion is destined to change the entire face of Europe." Those were prophetic words, and it was remarkable how true they had

(The Mayor of Salford.)

proved. The present was not the time to go into the historical development of the spinning and weaving machinery in these manufacturing districts. The first wheel-cutting machine had been made in Manchester; the first self-acting lathe designed by Richard Roberts was in fact still in existence at Messrs. Beyer and Peacock's works. Not only had this district had some influence on mechanical engineering, but the reign of law in connection with engineering had received the benefit of the work of Whitworth and of Joule. The latter had been born in Salford, he was proud to say; and it was impossible to refer to engineering formulæ without mentioning his name. He should have been glad if Salford could have figured more prominently in the arrangements for the meeting; but the programme was so full that even when he had wanted to provide some sort of entertainment he had found it utterly impossible to do so, in consequence of the many offers that had been accepted from all parts of the district of South Lancashire. He could only say on behalf of Salford that they would be happy to show everything they had in the gas works, the sewage works, or other undertakings; and he desired to offer the members a cordial welcome to the borough. The archæologists were going to Salford in great numbers; they would no doubt find a great deal of antiquity there, and antiquity was not to be despised. Successful engineers were those who were well acquainted with the doings of the great engineers of the past. It was only by studying antiquity and noticing the failures and successes of their predecessors that they could hope or expect to avoid failure and achieve success in the future. He was glad to have listened to the welcome offered by Alderman Thompson; and he desired to join heartily in congratulating both Manchester and Salford on the presence of the Institution of Mechanical Engineers. They were a great society; and he was sure that the two towns would jointly do their best to make their visit pleasant and profitable.

The PRESIDENT desired on his own behalf, and on behalf of his colleagues and the members of the Institution generally, to offer their best thanks for the kind welcome accorded to the Institution in Manchester. It always gave them great pleasure to meet in the

summer, and to combine a certain moderate amount of amusement with a large opportunity of improvement and instruction. As engineers it gave them the greatest pleasure to meet in Manchester, perhaps the most interesting city in the country from their own particular point of view; and he need hardly say that it gave them all the greater gratification to come, when they were welcomed so heartily by the municipal and the academical authorities as well as by their technical brethren generally, as they had been welcomed by every one on the occasion of their present visit.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and the following fifty-two candidates were found to be duly elected:—

MEMBERS.

Armour, James Glencairn,	Liverpool.
Arnot, William,	Glasgow.
Baldwin, Arthur Hugh,	Manchester.
Butterworth, Joseph,	Manchester.
Churchward, George Jackson,	Swindon.
Clarkson, Charles,	Liverpool.
Deakin, Benjamin Walter,	London.
Dunell, George Robert,	London.
English, Thomas Matthew,	Bombay.
Ennor, Charles John,	Oporto.
Fowler, Robert Henry,	Leeds.
Hall, Henry Platt,	Oldham.
Harmer, Oscar,	London.
Herriot, William Scott,	Demerara.
Higginbottom, Lloyd,	Manchester.
Kiernan, George,	Manchester.
Liebert, Henry Anton,	Manchester.
Mann, James Hutchinson,	Leeds.

Murray, Thomas Roberts, . .	Glasgow.
Nicholson, John, ...	Venezuela.
Oka, Saneyasu, ...	Osaka, Japan.
Platt, John, ...	Manchester.
Pollitt, Harry, ...	Manchester.
Reed, Joseph William, . . .	Jarrow.
Robinson, Arthur Maurice, . .	Rochdale.
Robinson, Charles John, . .	Rochdale.
Robinson, Mark Heaton, . .	Thames Ditton.
Sankey, M. H. P. Riall, . .	Thames Ditton.
Saxon, George, ...	Manchester.
Scott, Robert, ...	Calcutta.
Seymour, Louis Irving, . . .	London.
Shand, John, ...	Edinburgh.
Stevens, Thomas, ...	Kingston-on-Thames.
Touch, John Edward, . . .	London.
Woods, William Henry, . .	Manchester.

ASSOCIATE MEMBERS.

Anderson, Tom Scott, . . .	Sheffield.
Davey, Edward Ernest George, .	London.
Fendick, Walter, . . .	Hemel Hempstead.
Fitz-Gerald, John Fredk. Gerald, .	London.
Hawley, Cecil Edward, . .	London.
Hyde, George Herbert, . .	Colombo.
Monckton, Charles John, . .	High Wycombe.
Raleigh, Charles, . . .	Johannesburg.
Sutton, Hugh Reginald, . .	Reading.

ASSOCIATE.

Peters, Lindsley Byron, . .	London.

GRADUATES.

Hollingsworth, Edward Massey, .	St. Helen's, Lancs.
Mansfield, Alfred, . . .	Calcutta.
Readhead, Robert, Jun., . .	South Shields.

Russell, William Colin, . .	Briton Ferry.
Simpson, Lightly Stapleton, . .	Cambridge.
Suffield, Frank Wilson, . .	Birmingham.
Whitelegg, Robert Harben, . .	Plaistow.

The following Papers were then read and discussed :—

"Description of the new Electric Lighting Works, Manchester;" by Dr. John Hopkinson, F.R.S., Member of Council.

"Electric Welding;" by Mr. Benjamin Alfred Dobson, Member of Council.

At One o'clock the Meeting was adjourned to the following morning.

The Adjourned Meeting was held in the Owens College, Manchester, on Wednesday, 1st August 1894, at Ten o'clock a.m.; Professor Alexander B. W. Kennedy, LL.D., F.R.S., President, in the chair.

The Discussion upon Mr. Dobson's Paper on Electric Welding was resumed and concluded.

The following Papers were then read and discussed :—

"Description of Twin Screw-Propellers with Adjustable Immersion, fitted on Canal Boats;" by Mr. Henry Barcroft, of Newry.

"Description of the Manchester Main Drainage Works;" by Mr. Wm. Thomas Olive, Resident Engineer.

The remaining Papers announced for reading and discussion were adjourned to a subsequent meeting.

The President proposed the following Votes of Thanks, which were passed with applause:—

To the Council of the Owens College, for their kindness in inviting the Institution to meet in the College, and for the facilities offered for the Meeting.

To the Executive Committee—particularly the Right Honourable the Lord Mayor as Chairman, the Right Worshipful the Mayor of Salford as Vice-Chairman, and Mr. Charles Hopkinson as Honorary Secretary—for the admirable arrangements they have made for this Summer Meeting of the Institution in Manchester, with a view to the convenience and enjoyment of the Members.

To the Right Honourable the Lord Mayor, Sir Anthony Marshall, for his handsome reception of the Members at his Conversazione; to the Local Members who provided the gala performance at the Theatre; to the Proprietors of the numerous Engineering Works and other Establishments open to be visited; and to the several hosts who have arranged for so hospitably entertaining the Members on the occasion of their visit.

To the Directors of the Lancashire and Yorkshire and the London and North Western Railway, for their kindness in affording special facilities for the Excursions over their lines.

The Meeting then terminated at One o'clock. The attendance was 378 Members and 61 Visitors.

DESCRIPTION OF THE NEW ELECTRIC LIGHTING WORKS, MANCHESTER.

BY DR. JOHN HOPKINSON, F.R.S., MEMBER OF COUNCIL.

Progress of Electric Lighting.—It is now more than fifteen years since the author had the honour of bringing before this Institution his first paper on Electric Lighting (Proceedings 1879 page 238). Since that time this department of practical science has undergone an extraordinary development. Then the only electric lights were arc lights; the first incandescent lights in a practical form were not made until nearly a year later. Now there are many millions of incandescent lights in daily use. The machine experimented upon by the author in 1879 was what would then have been considered a fairly large one and highly economical; it required about 6 horse-power to drive it. Today there are many machines which have been working for a considerable time, requiring upwards of 1,000 horse-power to drive them. Then the commercial efficiency of the machine was about 50 per cent. Today it is a matter of common practice to produce machines having commercial efficiencies of 94 per cent. The purpose of the earlier paper was to lay before this Institution the results of certain tests made upon a single machine, the methods of which tests seemed likely to be of general utility, as has since proved to be the case. The purpose of the present paper is merely to give a short description of the Electric Lighting Works in Manchester, more particularly stating the minor points in which the arrangements differ from those most generally adopted. Although the differences from ordinary practice are small and comparatively unimportant, and involve nothing new in principle, a description of these works may be of interest on the occasion of the present meeting being held in Manchester, when the works themselves will be accessible to the Members of the Institution.

System of Distribution.—The system adopted is a direct continuous current, with five conductors supplying consumers at a pressure of 100 volts, the total pressure between the outer conductors being 400 volts. The conductors are partly bare copper in concrete culverts, and partly india-rubber insulated cables in cast-iron pipes. In Fig. 5, Plate 70, is shown a transverse section of the culvert in Portland Street. This arrangement of conductors is very similar to that which has been adopted in many other places, but is here carried out on a somewhat more extensive scale, the Portland Street culvert containing a total area of copper of $9\frac{3}{4}$ square inches. It will be observed that the sectional area of the three intermediate conductors I is small, only $\frac{1}{4}$ square inch for each; whereas the total sectional area of the outer conductors in this case is no less than 9 square inches. As might naturally be expected, such small intermediate conductors are in themselves inadequate to effect a perfect balance; the balance is therefore perfected by means of motor-generator machines fixed in outlying parts of the system. One of a pair of such motor-generator machines is shown in Figs. 15 to 17, Plates 74 and 75. Each of these machines is wound with two circuits CC, so that the pair contains four circuits, each circuit being connected with two conductors of the five-wire system. The two machines being connected mechanically with each other by the coupling B, shown to a larger scale in Figs. 18 and 19, any excess of current demanded from one section will be supplied by the circuit connected thereto, and the power required to effect this supply will be derived from one or more of the other circuits. As a compensating device this arrangement is found to work perfectly; it does not claim any originality, as it has been in use for some time in many places. Electricity can be supplied to consumers at four different pressures, according to their requirements.

Insulation.—The system of bare conductors has the disadvantage that the general insulation is poor; but this really causes no trouble, as it is a general small leak over the whole system, and does not tend to get worse. There is one curious fact in connection with this defective insulation; the insulation of the positive conductor is

always good, while that of the negative is always bad. The fact has been generally known for some time, but the author did not realise its importance till he experienced it. Electrolysis will deposit upon the negative conductor hydrogen from the moisture on the insulators; hence this exceptionally defective insulation is not calculated to injure the conductor. The explanation, so far as the author is aware, was not known. The difference in insulation between the positive and negative conductors arises from electric osmosis, which may be explained as follows. Suppose two vessels containing water to communicate by a cotton wick, and two electrodes differing much in potential to dip into the two vessels; then it is found that water passes over continuously from the vessel into which the positive electrode dips to that into which the negative electrode dips; this fact has long been known to physicists as a laboratory experiment. Next suppose two electrodes to be carried on porcelain insulators which dip into water, and the water to be maintained at earth potential, and the two electrodes to be one positive and the other negative; then if the current leaking from each electrode into the water be measured, it is found that the leak from the negative is many fold the leak from the positive; this experiment the author has himself tried. The action of bare conductors is the same upon a large scale. The main source for moisture is from the walls and floor of the culvert; this moisture will constantly creep over the porcelain insulators PP in Fig. 5, Plate 70, towards the negative conductor, but will creep away from the positive conductor, drying the neighbourhood of the latter and improving its insulation. With the five-wire system the troubles have been few, and all easily met; with the bare conductors there have been no troubles at all.

Switchboards.—The switchboards are very simple and compact; Plate 73 shows one of them for the feeders. The latter are connected to the vertical bars, each feeder to one or other of a pair of bars through a single two-way switch S at the bottom of the pair of bars. The pole of each dynamo machine is connected through a switch to a horizontal bar of its own; and the horizontal and vertical bars

are connected to each other by removable screw-plugs. Suppose feeder No. 1 is connected to machine A through the left-hand vertical bar, and that it is desired to change this feeder to machine B. For this purpose the screw-plug is put in for connecting the horizontal bar of machine B to the right-hand bar of the feeder, and the switch S is thrown over, so as to connect the feeder to the right-hand bar and to disconnect it from the left-hand bar; the change is thus effected in a fraction of a second. The double switches at the end of the horizontal bars have to do with exchanging from one machine to another. A resistance of about 3 ohms is permanently interposed between the two sections of each switch, and one section is permanently connected to the conductor from the machine. On each bar is an ampère indicator, competent to show when the current is nil. Suppose it is desired to take work off machine C, and put in D in its place: first the horizontal bar of D is connected by screw-plugs to all the vertical bars through which C is working, and machine D is started running; next by the double switch machine D is connected to its horizontal bar through the resistance of 3 ohms; then the indicator is watched, and as the speed of D rises the current passing back from the system of conductors through D will diminish; at the moment when it is nil, the resistance is short-circuited by the same double switch, thereby connecting D direct to its bar. Machine C is now slowed down, and at the moment when its current is shown by its indicator to be nil it is switched out, and the change is completed. It will be observed that the machines may each be run at the pressures suited to the feeders with which they are connected.

On the five-wire distributor board there are six sliding glass-plates with holes through them, two holes in each plate, for ensuring that it shall be impossible to put plugs into wrong places, and for preventing thereby the serious consequences which would follow such a mistake.

Engines and Dynamos.—The general plan, Plate 67, shows the relative positions of the various portions of the machinery, and Plates 68 and 69 are cross sections of the engine house. In the first instance six engines and six dynamos of about 100 HP. each were put

up, and also four engines and four dynamos of 400 HP. each. The six smaller dynamos give nearly 600 ampères at a little over 100 volts; the four larger give 600 ampères at a little over 400 volts. The engines are all vertical compound condensing, and drive their respective dynamos by link belts, carried under jockey pulleys, Fig. 4, Plate 70. The jockey pulleys work in every respect as well as simple belts of adequate length; and the loss of power is increased to only a very small extent, if at all. Compared with ordinary belt driving, the saving in space is considerable. In comparison with high-speed direct driving there is the advantage of entire freedom as to speed, both of engines and of dynamos; and there is less liability to vibration. On the other hand high-speed engines take less space, and the author thinks if single-acting they make less noise. In his opinion there is no great balance of advantage in one system over the other.

The condensers are ejector condensers, the condensing water being lifted some 30 feet in order to give an adequate head. These condensers have been found effective, giving a vacuum of 25 inches; and they prove most convenient.

The regulation of electric pressure is effected by adjustment of the governor whilst running. Two more engines and dynamos of 400 HP., exactly like those already erected, have been ordered after the experience of last winter.

Boilers.—The boilers are of Lancashire type, 30 feet long and 8 feet diameter; at present they are six in number, and a seventh is now being added. They work at a pressure of 125 lbs. per square inch, and are fitted with mechanical stokers, and the water is heated by economisers. The steam-pipes, feed-pipes, valves, and economisers, are all in duplicate. The boiler house, 77 feet long by 70 feet wide, is covered from end to end by a steel water-tank weighing about 160 tons, constructed in seven compartments, and holding 205,000 gallons of water. The general construction of the tank is shown in Plates 71 and 72.

From the general plan, Plate 67, it will be seen that, in addition to the engines already on order, there is room for eight more large

engines and five additional boilers. Hitherto no accumulators have been used; but in the author's opinion the present reduced price of these and their increased durability justify their introduction into large stations as well as small. There will of course be no difficulty in adding them when it is desired.

Work.—There are connected to the mains 18,600 incandescent lamps of 16 candle-power, 250 arc lamps, and motors to the extent of 16 horse-power. This is an encouraging result when it is remembered that a preliminary supply on the two-wire system was begun only just a year ago. The average price to the consumer up to 31st March was about fivepence halfpenny per unit.

In conclusion the author wishes to express his thanks to three gentlemen who have contributed much to the substantial success of the undertaking: namely to Alderman Lloyd Higginbottom, the able mechanical engineer and vice-chairman of the electric lighting sub-committee, for his constant advice in all matters, whether engineering or commercial; to Mr. Charles Hopkinson, who designed the buildings; and to Mr. C. H. Wordingham, formerly the author's assistant, and now Engineer of the station. He has also been not a little indebted to some of those who have contracted for the work; but they are many, and it would be invidious to distinguish.

Discussion.

The PRESIDENT understood that Alderman Higginbottom, whose name had been referred to in the paper, had been devoting his attention to this subject for a long time; and it would be of interest to the members if he would tell them something about the first year's working of the station, the accounts of which had now been published.

Alderman Lloyd Higginbottom desired to thank the author for the kind way in which his name had been mentioned in connection with the work of the electric station in Manchester. As first laid out the works had been intended to supply the demand in Manchester for at least three years. It had been contemplated by everyone concerned in the matter that the demand would not at first be great; but in the course of five months the whole of the power provided for had been virtually taken up, and a large extension had now to be made for the coming winter. The commercial results of the first year's working—eight months only—were considered to be highly satisfactory. The extra costs, connected with all the little troubles that had had to be encountered at the beginning of the year, had been charged to revenue, and not to construction. Although there would have been ample justification for charging a certain amount of these extras to capital, it had been thought advisable that at any rate the first year should be cleared off; and the expenses had consequently been all placed to revenue. The total cost had been £127,375, including £39,014 for the purchase of the land. The result of the eight months' working had been that the revenue was £10,198, and there was a debit balance of only £210. The demand at present was so great that all the power which was being provided for the coming winter had already been taken up; and next year it would be necessary to make a still larger extension for the further demands that would arise. From all parts of the city, outside what was called the compulsory area, there was a great demand; and application would have to be made to the local government board for power to borrow money in order to lay mains throughout that enlarged area, as had of course been contemplated at the first. It was estimated, almost with certainty, that the revenue for the present year would amount to nearly £25,000: so that, instead of any debit balance, there would be indeed a handsome credit balance towards reducing the rates of the city. For the first year a certain heavy loss had been anticipated; but as it was, there had been only a small debit balance. If the corporation had been a private company, they would have paid a dividend; but as a corporation they had to provide for three things: first, for depreciation at the high rate of 10 per

(Alderman Lloyd Higginbottom.)
cent. upon machinery; secondly, for interest on borrowed money to carry out the works; and thirdly, for a sinking fund to pay off the money borrowed. With these three charges on the capital account he thought the small debit balance of only £210 was highly satisfactory.

Mr. THOMAS PARKER was glad to hear the statement of the success which had been achieved, and should like some information as to the working of the motor generators, and the manner in which they were employed, having himself been instrumental in introducing them, first at Chelsea, then at the Crystal Palace, and afterwards at Oxford. They had been running at Oxford for three years, and had done good work. The mode of their employment was different from that adopted in Manchester, which appeared to him to be less efficient; but this could only be known by taking the whole system into consideration. Any statement as to their behaviour, and the amount of energy they took in proportion to the work done, with the services they rendered in the system, would be most interesting.

Mr. C. FREWEN JENKIN asked for some information about the amount of energy transferred from one circuit to another with a given difference of voltage.

Mr. CHARLES HOPKINSON, having been concerned with the buildings for the station, considered that, so long as the machinery was satisfactory, it would be sufficient for the members to recognise, when visiting the works, that the buildings were adapted to it. Externally they might perhaps have a doubt whether the importance of the station was sufficiently emphasized, owing to his having had to adapt appearances to the economical tendencies of the corporation. Naturally he should have liked the building to have some amount of ornament; but instead of that it had the greatest severity of style. The arrangement made was for the greatest simplicity of working in every respect; and the buildings were designed with that view. If the arrangement for the machinery was simple, the arrangement for the building was also simple. It was easy to keep clean; and

inside at any rate it was of a design intended to show a due appreciation of the value of the machinery it contained.

The President asked whether there had been any difficulty with the foundations, owing to the watery subsoil of the locality. It was mentioned in the paper that a special tank had been made to cover the boiler house; and he thought some further particulars respecting its construction would be of interest.

Mr. Charles Hopkinson said the foundations were one solid mass of concrete upon a bed of tough clay, embracing the whole foundations of the dynamos and the engines. The consequence was that as there was so large a mass of foundation no vibration was transmitted outside the building.

In order to avoid wasting space by carrying in the ordinary way the weight of a tank containing 205,000 gallons, he had suggested that the tank should go right over the boilers in a single span; and his brother had designed the tank so as to carry out that suggestion. As shown in Plates 67 and 71, the only support between the back wall of the engine house and the outside wall of the boiler house was a row of steel pillars along the front of the boilers, leaving two spans of 43½ and 28 feet for the continuous girders carrying the tank. The supporting pillars were 11 feet apart, Fig. 6, Plate 71, and between each pair of pillars one boiler was put in, so that no space was wasted. The girders themselves were contained in the depth of the tank, Plate 72, so that no headroom was wasted. The water space extended below the depth of the girders, as shown in the transverse sections, Figs. 6 and 11, because the bottom of the tank was dished, so that all the plates were in tension; and the girders themselves formed the partitions between each section, so that the water in each section could be let off separately. In the engine house the method by which the centre of the roof was carried was shown in Plates 68 and 69. The central gangway was provided by dividing the pillars into two. Each pillar, regarded as a support for carrying the roof, consisted of two steel upright girders of H section set on end, which were braced together by

(Mr. Charles Hopkinson.)
cast-iron brackets, halfway up and at the top. In that way there was a free open gangway right through between the engines at two levels. Above these gangways were laid the steam and exhaust pipes, which were thus readily accessible, and at the same time quite out of the way of the travelling cranes commanding the building.

Mr. Jeremiah Head, Past-President, observed that the engines for generating electricity were two-cylinder compound engines, and that the pressure in the boilers was 125 lbs. per square inch. In view of the great extensions which seemed to be necessary and to be contemplated for next winter and the year after, he enquired whether that would not be a favourable opportunity for making the engines triple-expansion, with a much higher pressure in the boilers. This had been done in other parts of the country for the generation of electricity; and as the saving of fuel seemed to be greatly desired, he thought it would be an excellent opportunity for arranging to work with higher pressures and with triple engines instead of two-cylinder compound. In the paper it was stated that the engines now on order were simply duplicates of those at present used.

Mr. J. Hartley Wicksteed, Member of Council, asked for some description of the ball bearings illustrated in Plate 76, which he understood were used for the motor generators shown in Plates 74 and 75.

Mr. Graham I. Francis, of the Auto Machinery Co., Coventry, having supplied the ball bearings shown in Plate 76, explained that they were fitted to the motor generators with the view both of economising power by reducing the friction, and also of overcoming as far as possible any liability to stoppage through want of attention on the part of the workman in charge of the machines. A small dynamo fitted with these bearings had been running at 1,300 revolutions per minute continuously for nine hours without oil or any attention whatever, and without any signs of heating. Readings taken from the ammeter every fifteen minutes during the running showed a gain in pressure of about 10 per cent. over similar readings

taken the day before, under as nearly as possible the same conditions, when the dynamo was fitted with the ordinary bearings. In the construction of ball bearings required to run at a medium or high speed, the first point to be kept in view was that both the balls and their races must be made from steel of the highest quality and as hard as possible; for owing to their small bearing surface they would speedily wear out of truth if soft. Iron case-hardened had been tried, but had proved to be a failure, because the surfaces soon gave out, and then caused far more friction than ordinary bearings. The second essential was that the ball bearings should be entirely self-contained and easy to adjust, so that, without any special training, any ordinarily intelligent fitter could put them together, fit them in place, and adjust them for running. In many bearings the only possible way of getting the balls in place was by sticking them upon the races by means of fat; and with balls of any considerable size this was a most difficult job. In the bearings shown in Plate 76 the balls were readily got into position by slipping the first of the rings R over the flanged sleeve S, which was held with the flanged end F uppermost. The first row of balls was then placed on the ring, and held in position between the ring and the flange, while the whole was turned the other way up. The second row of balls was then added, and was held by the second ring, and so on; and finally the loose flange L was put on, and the whole held together by the two nuts N. The complete bearing could then be put into the bracket or pedestal, which was bored accurately to fit the rings, and could be sprung slightly open to allow the balls to adjust themselves properly; and the whole was adjusted by the nuts N until the sleeve turned freely without the slightest shake. The bearings were then ready to be fitted to the shafts. The sleeves S were made to fit the shaft snugly, unless lateral motion was required, which was sometimes advisable in dynamos &c. In the small dynamo already mentioned they fitted freely, and were kept in position by a small sunk key K, as shown in Fig. 20. The number of cone rings R depended upon the number of rows of balls required to carry the load; and they were all formed at an angle of 45° to the axis of rotation of the balls. By this arrangement each

(Mr. Graham I. Francis.)

series of balls was adjusted from the single pair of nuts N. The balls were readily got into position; and the whole bearing could be made for a reasonable sum, considering the high quality of the work required. Specimens of the balls were shown from 1-8th inch to $3\frac{1}{2}$ inches diameter. The largest sizes were made from the hardest steel that could be got; and on account of the great risk in hardening such a large mass of solid steel, they were left in their normal condition of temper. These balls, being used chiefly for bridges and similar work where the rolling motion was slight and slow, were found to answer the purpose well. He showed part of a lathe bearing which had been running for the last seven years in constant daily use; and it would be seen that there was no sign of wear on the balls or on the sleeves. Another specimen exhibited was a small lathe-spindle which had been running about eighteen months; it was made on exactly the same plan as the dynamo bearing, and also showed no signs of wear. The method of making the balls from the bar was illustrated by a specimen in which several of the balls were already partially formed, ready for severance from the bar and for completion. The adjustment was shown by a small model of the bearing in the bracket or pedestal, showing the clipping arrangement for holding the rings. It would be noticed that the rings were made rather thick, because if they were not stiff enough it was surprising how easily they could be sprung out of round. With the view of overcoming this objection the rings were now made extra stiff and strong; and care should be taken not to tighten them up too much in adjusting the bearing, but only just sufficiently to keep them from moving. The crushing strain of the balls varied approximately as the square of the diameter: a half-inch ball crushed at about from 10 to 14 tons, and a one-inch ball at from 40 to 54 tons. But owing to the strains set up in hardening, especially in the larger sizes, a very low factor of safety must be taken; one-tenth of the crushing load was what was generally taken as a safe working load.

Mr. William H. Maw, Member of Council, asked whether the jockey pulleys on the link belts driving the dynamos were specially

weighted, so as to apply a constant tension on the belt; and if so, what the amount of load was. There appeared from Fig. 4, Plate 70, to be a screw adjustment; and he should like to know whether the jockey pulleys were screwed down dead, or whether they were left free to yield to the pull of the belt. Of link belts there were two kinds that were largely used: those in which the links were of the same size all across the width of the belt, and those in which they were shaped to fit the transverse rounding of the rim of the pulley. He asked whether the belts here used were shaped belts, or whether they were made with plain links all of the same size; also whether there had been any necessity to take them up largely during the time they had been running. Any stretch would of course be shown by a large drop in the jockey pulleys. Under somewhat similar circumstances he had used a jockey pulley running on a belt which was sewn up solid without a lap joint; it was an 18-inch belt running at 3,000 feet per minute, and it had been running for thirteen years without the slightest trouble being experienced from the action of the jockey pulley. It had proved satisfactory in every way. In that instance the belt was not so short as that shown in Fig. 4; and the jockey pulley was not screwed down, but was mounted so that it could ride on the belt freely.

Mr. C. H. Wordingham could confirm what had been said in the paper as to the perfectly satisfactory way in which the works were running: there had been no trouble of any kind with the engines, the dynamos, or the mains; everything had gone on with perfect smoothness since he had been in charge. Judging from the experience thus far obtained, the five-wire system he thought was no harder to work than the three-wire system. The troubles met with were of the same nature on either system, arising chiefly from the balancing of the currents; and these difficulties had been entirely overcome by the use of the motor-generator machines. Taking the mains all round, he considered they were the most satisfactory of any that had hitherto been laid. It was true that the insulation of the bare copper mains was not high; but the

(Mr. C. H. Wordingham.)
materials of which the conductors and the insulators were composed must be permanent. They were exceedingly convenient conductors, and the first cost was small. Perhaps the best testimony that could be given to their success was the fact that it was intended to use bare copper in the further extensions about to be made.

Professor W. H. Watkinson asked what was the consumption and cost of the coal used. It seemed to him that a higher efficiency throughout the whole working would be obtained, if, instead of using Lancashire boilers, high-pressure water-tube boilers were employed, and the engines were arranged so as to work practically without expansion at the maximum load, thereby working both boilers and engines with the least economy at the maximum load, which lasted only a short time, and with a maximum economy at the mean load.

Dr. Edward Hopkinson drew attention to the action of the transformers or motor-generators, with regard to which the figures that he had obtained were interesting. The resistance of each half of the armature of the transformer was 0·0125 ohm, making for the two sides 0·025 ohm. Consequently 100 ampères could be transferred from one side to the other, making a difference in the balance of 200 ampères, with a loss of only 2·50 volts; this was the measure of the value of the transformers, a matter of great importance in the regulation of the system. These transformers had been made with ball bearings, as already described, which had had the effect of largely reducing the friction in the bearings. Although the machines were only of small size suitable for transferring 100 ampères from one side to the other, the combined efficiency of the double transformation was over 85 per cent., showing a commercial efficiency of 92 per cent. for each machine. This was a good result, to which no doubt the ball bearings had contributed. With regard to the large generating dynamos, some of which had been made by his firm, Messrs. Mather and Platt, it was of interest to observe that the extraordinarily high commercial efficiency of 95 per cent. had been obtained.

Mr. T. Hurry Riches, Member of Council, had made some little use of ball bearings, and still more of roller bearings. His experience had been that, so long as either the rollers or the balls were entirely new and of uniform diameter, so that they would keep apart in running, there was little objection to them, and the friction was minimised; but when any appreciable wear had occurred, the hardest balls or rollers retained a larger diameter, and over-ran the others, causing a considerable amount of additional friction as soon as they came together, because the contiguous surfaces of the adjacent balls or rollers were of course running in opposite directions, and dragging against each other, thereby greatly increasing the friction, and producing a tendency to jam each other. To avoid this difficulty he had inserted between the adjacent rollers or balls a free roller of smaller diameter, which did not carry any of the load, but was itself carried in a pair of live rings, clear of the roller path or ball race: as shown in Figs. 22 to 25, Plate 77, which represented the roller bearings he was using for the carrying wheels of the steam traverser in the locomotive running shed at Cathays, Cardiff (Proceedings 1884, page 247). The surface of this intermediate roller was always running in the same direction as that of the roller or ball in contact with it on either side; and under all conditions therefore, whether some of the rollers or balls got smaller than the others or not, it materially diminished the friction and improved the ultimate running.

Mr. Thomas Parker thought that, valuable though ball bearings no doubt were for certain applications, their use in the motor generators scarcely afforded a good test of their efficiency. For it was easy to imagine that, if the motor generators were properly balanced, their spindles would hardly exert any pressure on the bearings; and thus it might be that the balls were called upon to do an insignificantly small amount of work in that position.

Mr. Joseph Adamson had no doubt the ejector condensers mentioned in the paper were effective; but he should like to know why they were adopted, and whether they were economical.

Mr. John Barr also asked whether the ejector condenser was considered as economical as a surface condenser or a jet condenser. It was stated that the condensing water was raised 30 feet in order to give an adequate head; and he enquired whether the question of the power so expended had been gone into as affecting the economy of this method of condensing.

Mr. Bryan Donkin asked whether there had been any experiments with regard to the consumption of steam in these engines.

Dr. John Hopkinson was glad that so much had been said on the question of ball bearings, which he had refrained from introducing into the paper, merely in order to avoid giving them an undue prominence in relation to the other parts of the work. Ball bearings which he had in use at his own house with a small dynamo machine had now been working nearly a year with perfect satisfaction, the machine running at about 1,400 revolutions a minute. The best testimony to their efficiency was that his stable-boy, who had charge of the machine, had never let him hear anything about them: so that his experience of them was simply that they had been in use during that period, and that he knew nothing further about them. The advantageous way in which the motor generators worked was due to the high speed at which they were run, namely 1,400 revolutions a minute, or thereabouts. In consequence of this it was possible to get an economical machine with low electrical resistance; and for this particular purpose it was of course essential that there should be a low resistance, otherwise, when the load to be transferred became at all considerable, the fall of potential would also be considerable. As a matter of fact the loss in ordinary transfer might be said to be inappreciable. The motor generators were here used in a way different from that in which they had already been used in the instances mentioned by Mr. Parker (page 304). Here they had not to deal with any substantial part of the power transmitted, because they had really nothing to do with the transmission of power, but merely with the equalisation of any

little difference between one side of the conductors and the other. There were already four of these machines in use at different outlying parts of the system, and four others at the station itself. The object of the four latter was to enable the central station to run with only one of the small engines during the times when the load was light, and to effect equalisation throughout the conductors when only the one engine was in use. The four former were placed in two cellars in different parts of the system, in each of which there was a pair of these motor-generator machines mechanically coupled; these machines completely got over the difficulty of inequality of load, notwithstanding the fact that the size of the intermediate conductors was reduced in Manchester much below what had been the general practice. For small central stations he could not advocate going so far in reduction of the size of the intermediate conductors, because it was desirable to avoid the necessity for introducing anything like these motor generators except in connection with a large station. The motor generators had given complete satisfaction, and had annihilated all cause of trouble from inequality of load between the different sections of the system.

With regard to the water tank forming the roof of the boiler house, he doubted whether for its capacity and for its position any tank had ever been made so cheaply as this. From the way in which the weight was carried by the deep girders contained in the depth of the tank and by the dished plates forming the bottom, a benefit resulted in the minimum quantity of material being required.

It had been suggested by Mr. Head (page 306) that triple-expansion engines might be used with advantage in the Manchester station. Apart from the question whether it would have been more desirable in the first instance to put in triple-expansion engines, it appeared to him that at the present time it would be doubtful policy to vary the type, now that engines had been adopted which were giving thorough satisfaction. Unless there was strong reason to the contrary, there was great convenience and advantage in the duplication of parts, as far as this could be carried out. In working an electric lighting station, the cost of the coal was after all only one item; and absolute convenience he thought was on the whole of still greater moment.

(Dr. John Hopkinson.)

The jockey pulleys (page 309) were not weighted or loaded, but were held rigidly by means of adjusting screws. The most advantageous mode of using such pulleys he considered was to bring them down as lightly as possible on the belt, only just enough to ensure that the belt should bite. The result then was that the belt passed under the jockey pulley with an almost free bend, touching it over only a small arc; and when this was the case it appeared to him that any loss arising from the use of jockey pulleys must be exceedingly minute. A portion of the weight of the pulley was borne by the belt, and consequently did not come upon the bearings of the pulley, the friction of which must therefore be but small. If it were worth while it could be reduced still further by ball bearings; but he thought the friction was not of such moment as to make it worth while doing so. Another source of loss was the friction in bending the belt; and no doubt the bend under the pulley did occasion a small increase of friction. With a link belt at all events this friction would depend in large measure upon the tension of the belt at the time it was bent; and as the jockey pulley was here applied upon the trailing span of the belt, the latter was under but small tension when bending under the pulley. For these reasons he thought there could be no doubt that the jockey pulleys, while economising space in a large measure, had practically no countervailing disadvantages. The small dynamo at his own house was driven by a little gas-engine, which had a driving pulley $4\frac{1}{2}$ feet diameter, and the pulley of the dynamo was something like $4\frac{1}{2}$ inches diameter, and was placed so close to the driving pulley as to be almost underneath it. The belt was no longer than was absolutely necessary to get round the three pulleys. The jockey pulley worked satisfactorily; indeed it had been three years in regular work without causing any trouble whatever.

The links of the belts were not shaped to the form of the rounded rims of the pulleys (page 309). But the cross bars of the belts were divided in the middle, and the two halves of the belt were joined by leather, so that it would bend pretty nearly as freely as the ordinary leather belt; it was found that it worked perfectly well. These link belts had of course had to be taken up from time

to time, as all belts had; but as far as he knew they had not been taken up more than was the case with ordinary belts used without jockey pulleys. As far as he could ascertain, there seemed to be a prejudice amongst mechanical engineers against the use of jockey pulleys in the way in which they were here used; but he could not in the least see what was the reason of such a prejudice; and until he could see some reason for an objection of that kind, he found a difficulty in endeavouring to remove it. His own experience of jockey pulleys had been that they were absolutely and entirely satisfactory, and he should not hesitate to put them in anywhere where driving by belts was adopted, and to pack in the driving pulley and the driven pulley and the jockey as closely as they could be packed together.

The coal consumption (page 310) for the six months' working during last winter certainly appeared high; but undoubtedly in another year it would be brought down considerably lower, though probably not so low as to be equal to the very best results. The higher consumption hitherto was no doubt partly due to the caution of those who managed the station. As was well known, it was essential to make quite sure that the light should not be stopped from any cause whatever. For this reason it had been the practice to keep a spare boiler always under steam, ready to be brought into use if anything went wrong with the other boilers. So long as the station continued small, this entailed a considerable loss of coal: a loss however which would be diminished when the station became larger as time went on. Then there had been the coal strike in the autumn of last year, which had increased considerably the price of the coal. For these reasons and especially in the first year he thought it could hardly be expected to get any useful figures from the coal consumption which it would be of advantage to state. Perhaps a year later, when the station had got thoroughly into working order, and when questions of minute economy had not to be put aside in favour of successful running, it might be possible to give the figures with advantage.

As to the ejector condensers (page 311), he was well aware that they would not give, within perhaps as much as an inch, so good a

(Dr. John Hopkinson.)
vacuum as could be obtained with jet condensers or surface condensers. The reason for putting them in here had been their exceedingly great convenience. The air-pump thus became absolutely independent of the engine, and the engine itself was thereby simplified. No trouble had been experienced with them, and engines fitted with them were worked with as much ease as an ordinary high-pressure engine, and with greater convenience than an ordinary condensing engine, and also with the incidental advantage that condensing engines had when running with a light load. If everything had now to be begun afresh, he was sure that those who had had to work the station would be strongly in favour of having ejector condensers put in again. The matter of convenience in the working of a central station appeared to him to deserve more consideration than minute economy of coal. It was no doubt true that a little more coal was used with ejector condensers than with surface condensers; but he thought it was buying cheaply the greatly increased convenience obtained.

With regard to the steam consumption (page 312) there had been no definite tests up to the present time. Probably when the extensions now in progress were less engrossing, steam tests would be made; and whenever this was done he was sure Mr. Wordingham would be pleased to give the results of any experience he might obtain.

The PRESIDENT was sure the members would wish to accord to Dr. Hopkinson a hearty vote of thanks for his paper and for the remarks that he had made. Those who had not yet seen the electric lighting station, but who were going to see it this afternoon, would he was confident be extremely interested in it and learn something from their visit, no matter how great their experience might have been in that particular direction. It was certainly one of the most interesting stations in the country; and he made this statement from a personal knowledge of a majority of the stations throughout the kingdom. All who had had to do with the management or the working of such stations would be interested not only in the station itself, but also in the remarks made by Alderman Higginbottom, and especially in his account of the straightforward way in which the

corporation managing the station during the first year had boldly treated it as if it were in full running, and had written off the proper amount of depreciation, carrying everything to revenue instead of putting the greatest possible amount to capital. It was greatly to their honour, and greatly to the interest of the progress of electric lighting, when corporations and other responsible bodies in general treated matters in this way.

When the members were at the station, he wished to draw their attention to a matter touched upon by Mr. Charles Hopkinson (page 306), namely the arrangement of the steam and exhaust pipes. It was always difficult in large stations to get the steam pipes accessible and convenient to be duplicated, and yet out of the way of the travelling cranes. By the arrangement here adopted of a double column in the centre of the station the steam pipes were got exactly where it was most convenient to have them. They were quite accessible in every way, and they were duplicated, and yet they were kept altogether out of the way of the working gear of the station. That was a mechanical matter which he thought the members would be interested in seeing. He had naturally been interested in what Dr. Hopkinson had said about the insulation of the mains and the satisfactory use of bare copper, because he was a strong believer in the use of bare copper when it was possible so to use it; and certainly, now that it had turned out to be possible to use it under circumstances as difficult as those under which it was used in Manchester, its use might be considerably more extended than some engineers had anticipated.

The fact of the leakage being greatest from the negative conductor he was familiar with; and it was Dr. Hopkinson who had pointed out the reason of this. He should like to know whether any practical difficulty had been found in consequence of this earth on the negative, in cases where the Board of Trade wished the *middle* wire to be permanently earthed, as was the case with a five-wire system.

Dr. JOHN HOPKINSON replied that the Board of Trade insisted upon the middle wire being earthed. This obligation involved a

(Dr. John Hopkinson.)

certain loss, because there resulted a leakage going on the whole time from the negative conductor; and they should be glad to be set free from the obligation. So long as it was insisted upon by the Board of Trade it would have to be done. The Manchester station had not asked to be relieved from the obligation, but made the best of it.

ELECTRIC WELDING.

By Mr. BENJAMIN ALFRED DOBSON, Member of Council.

Experience in Electric Welding.—Practical everyday working for nearly three years of the process of Welding by Electric Force enables the author to give certain indications and appreciations of the method considered as a practical workshop operation. During this period his firm has had two machines in operation, worked from the same generating dynamo, and employed on different classes of work: one is specially arranged for piecing bar iron and steel; and the other and smaller machine for special classes of work of a more delicate description, such as brazing and the piecing of clean-finished work, where the fire heat would have destroyed the quality of the work on the adjacent material.

Mechanical Power.—The statement made with regard to the requisite mechanical power placed great difficulties in the way at first, as it was found that this power had been much understated. Having something like 35 indicated horse-power to spare on a certain engine, and understanding that 30 horse-power would be the utmost wanted in order to piece a 2-inch round bar, the author determined to drive the dynamo from this engine, particularly as it was in close proximity to the smithy and stretching shed, where this piecing was previously effected by means of the ordinary smith's hearth. By this practical test it was found that not 30 horse-power but as much as 80 horse-power seemed to be required for the larger sizes; and until this was understood, the engine was frequently stopped from want of steam, occasioning great loss and inconvenience. The company having control of the welding machine suggested that they should supply a semi-portable engine and boiler; and that this should be tried, with the option of purchase after a certain length of time, if approved. This was agreed to, and a portable engine by

Messrs. Marshall, of Gainsborough, capable of working up to 100 indicated horse-power with 80 lbs. pressure, was supplied and placed at a distance of about 45 yards from the welding machine. This got over the difficulty of power, but was of course more expensive on the score of separate attendance and other cost. But even with this engine it was found that, when piecing the larger diameters—and as yet nothing over $2\frac{1}{4}$ inches has been pieced—if the work was to be done within a reasonable time, the engine was seriously checked in speed. It was therefore with a view to be certain as to the basis of calculation for the necessary expenditure on driving power that the experiments which follow were conducted.

After some months' working with the portable engine, it was proved satisfactorily that the process was a practical one, and, so far as the results to the author's firm were concerned, a success. As considerable enlargements were about to be made to the establishment, a portion of a large dynamo room for electric lighting purposes was set apart for the welding dynamo and exciter; the distance of the leads from the dynamo to the welding machine was approximately 100 yards. Having a quick-running vertical engine of the kind made by Messrs. Fleming and Ferguson, making 140 revolutions per minute, with an extra heavy fly-wheel and abundance of surplus power, the author has been able to work the larger diameters without affecting the steadiness of the arc lamps driven off the same engine; and as the load will vary 80 horse-power in the tenth of a second, this result speaks well for the arrangement of the engine and for its governing powers. The greatest variation in voltage of the lighting dynamos has been two volts.

Electric Welding Process.—The following account of the principle of electric welding is taken verbatim from a paper prepared for a former meeting of this Institution by Mr. W. C. Fish, on the Elihu Thomson electric welding process.

"*Principle of Electric Welding.*—Every substance, whatsoever be its physical nature, is heated when traversed by an electric current; and the law defining the quantity of heat so produced is as precise and as clearly ascertained as is that of gravitation. The product

$C^2 R$—that is, the square of the current flowing, multiplied by the electrical resistance of any considered portion of the circuit—is directly proportional to the heat-units therein produced. For a continuous current, the resistance of an infinitesimal length of any conductor is inversely proportional to the area of its cross-section, and in metals increases with increase of temperature. Thus in iron the resistance increases some tenfold with a rise of temperature from 0° to 1000° centigrade. For alternating currents, which are usually employed in welding, the resistance of a conductor no longer varies inversely as its cross-section; but this divergence may be neglected without error in the description of the process, if not in the design of the welding machine."

The photograph in Plate 78 shows the alternating dynamo, the exciter, and the switchboard.

Another photograph, Plate 79, gives a view of the larger welding machine, showing clearly the method of clamping the work, in this instance a 2-inch round bar; and also the positions of the transformer, the rheostat or reactive coil, and the switches. Plate 80 gives a view of the same machine employed in welding a ring.

In the diagrams, Figs. 4 and 5, Plate 81, the welding machine is shown in front and end elevation. The transformer is represented in Figs. 7 to 10, Plates 82 and 83; and the reactive or choking coil in Figs. 11 and 12, Plate 83. In Fig. 6, Plate 82, is shown a general plan of two welders arranged in parallel, and their several connections.

Dynamo. — The Thomson-Houston welding dynamo is an alternating-current machine. The field-magnets project inwards from a cast-iron frame having six pole-pieces. Its speed is 1,000 revolutions per minute, and it gives at full load a current of 200 ampères at 300 volts, having a frequency of 100 complete alternations per second. The machine is excited from a continuous-current dynamo giving 40 ampères at a pressure of 110 volts. The large welder is capable of piecing iron or steel bars up to 2 inches diameter.

Transformer.—The primary coils consist of 41 turns of 0·452 inch copper wire; these are coiled round an iron core P, Figs. 4 and 5, Plate 81, formed of thin sheet-iron plates bolted together. The secondary circuit consists of a single massive copper tube T, $1\frac{3}{4}$ inch diameter inside and $3\frac{3}{4}$ inches outside, passing through the centre of the core P, and connected at the two ends with massive castings MM $6\frac{1}{4}$ inches broad by 3 inches thick, which support the welding clamps CC; one clamp is kept stationary during the welding, and the other is movable. The pressure is obtained by a screw and hand-wheel, forcing the movable clamp towards the fixed clamp.

Elihu Thomson Welding Process.—It has just been pointed out that the heating effect of the passage of electric energy through a bar of any particular resistance is proportional, not to the amount of energy, but to the square of the current simply. In order therefore to obtain the greatest heating effect with a given amount of energy, it is advisable to use a very large current at a very small pressure. With this object an alternating current is employed in the Thomson process, and transformed down from something like 300 volts to 1 volt or even a fraction of a volt. This reduction in pressure is accompanied by an exactly proportional increase in current; and the heating effect of the process is due to the passage of this enormous current through the bar which is to be welded. The bar itself is held between two clamps of copper having a small resistance; and the portion of the bar to be heated for welding is that which lies between the two clamps, and which always has a much greater resistance than the clamps themselves or any other portion of the circuit. Even therefore if a solid bar be held between the two clamps, it becomes heated somewhere between the points at which it is held. If however, as is the case for welding, the bar is not a solid one, but has a break in it at the point where it is to be welded together, then the greatest resistance in the circuit is at the surfaces of this break, where the contact is imperfect. Heat is developed here at once; and the surfaces being continuously pressed together by special apparatus, the metal as it softens is squeezed into closer contact, and eventually the two originally separate pieces are thereby

welded together. The resistance at the original break would of course become diminished as the metal becomes continuous by welding, if it were not even more increased by the rise of temperature, and the consequent fall in conductivity. In consequence of the latter however, the temperature of the metal at the weld continues to rise throughout the process until the current is finally cut off. The increase of resistance with temperature automatically necessitates also the uniform heating of the entire cross-section of the weld, because any cooler portions will be traversed by a proportionately increased flow of current until uniformity of temperature is obtained.

Good and Bad Welds.—It must not be imagined that a good weld can always be made by pressure alone. No doubt if the material were perfect in character and thoroughly homogeneous, this might be the case. The iron and steel of commerce are not perfectly pure; and in order to make certain that the work may be subsequently depended upon, it is advisable that the burr formed by the pressure should be reduced by hammering in swages. The machine shown in the photographs, Plates 79 and 80, has a screw and hand-wheel for applying the pressure requisite to give the welding action; and this machine has been found powerful enough, so far as its mechanical arrangements are concerned, for piecing iron and steel bars up to 2 inches diameter. The distance apart of the clamps—or, to put it in another way, the length of the projection of the material to be pieced—varies according to the nature of the material and the diameter or area of the weld to be made, and is, as can be well understood, proportionately less for the larger sizes and greater for the smaller. There are limits of course in both directions; but these limits are well within the machine itself, and a short practical experience teaches the workman the distance he ought to set his machine. Roughly speaking, for the smaller sizes the projection should be about three times the diameter of the piece, and for the larger sizes twice the diameter. When welding pieces of different diameter, the centre of resistance can be brought to the point of contact by varying the projection of the different diameters, and thereby equalising the

resistance in the projecting portions. Thus in piecing 1-inch and $1\frac{1}{2}$-inch bars, the 1-inch bar might have to project some 3 inches, and the $1\frac{1}{2}$-inch bar 2 inches, in order to bring the centre of resistance to the point of contact. This principle of difference of projection applies also when piecing metals of different quality. It is found in practice that the current should not be turned on to its full strength at the commencement of the operation; if this is done, the material under treatment is unnecessarily damaged, and the general life of the machine itself is injured. As the surfaces in contact become heated and the resistance is increased, the rheostat or regulator of power or choking coil, Fig. 12, Plate 83, is gradually turned to increase the volume of current; and immediately before taking out of the clamps for the purpose of swaging, the full power required is turned on for a second or two.

Method of Working.—The method of working is somewhat on the following lines, as indicated in the general plan, Fig. 6, Plate 82. The main carrying the current to supply the exciting coils of the alternator is conducted to the room in which the electric welder is placed. The main is attached to the terminal of a rheostat or resistance coil, and a return main is connected to the other terminal and is returned to the alternator, and from this another main is led back to the exciter. The rheostat now being in series with the exciting coils governs the current of excitation, and thus controls the output of the alternator. A double-pole switch has one pole connected with the primary main leading to the primary coil of the electric welder, and the other pole connected with the exciting-current main leading to the rheostat: so that this switch breaks the exciting circuit and also the primary circuit at the same time. When two pieces are ready to be welded, the double-pole switch is switched in, and the attendant adjusts the rheostat until the desired heat is obtained.

The ordinary surfaces of bars, whether cut by shears or broken with the chisel and hammer, are found sufficiently uniform to permit of welding, without further preparation. Should there be dirt or rust upon the surfaces, it is easily expelled when the metal is

sufficiently soft to allow of the end pressure of the screw necessary to form union, and the dirt, scale, or oxide makes its way to the exterior.

Work done.—In common practice at the author's works the following materials have been heated, and the undermentioned work has been performed. Welding of steel of every quality, iron of every description from crown to best roller iron and charcoal iron, steel and iron together, wrought-iron and cast-iron; different diameters of the same and different materials. Riveting in many varieties; work which previously had to be riveted cold, and which consequently left the strength of the parts uncertain, is now done easily and certainly with the requisite heat. The piecing of countershafts and lathe spindles, where the question of exactness of length is of the utmost importance; screwing taps, rollers and spindles broken in the neck bearings, and brazing of all descriptions, have all been successfully treated. The alloys which have been tried have been done more for the purpose of experiment than for any useful end; and were not successful, owing to there not having been time to persevere sufficiently for ascertaining the precise temperatures and conditions under which the process could succeed.

Power required for Electric Welding.—These tests have been confined to the welds required in everyday work, and have varied from $\frac{1}{2}$-inch steel and iron to 2 inches, as shown in Table 1 (pages 328–9). The measurement of the alternating-current power supplied to the welding transformers is attended with some little difficulty, owing to the short space of time during which the current and electromotive force are practically steady. As also every piece of iron varies in resistance, though cut from the same bar, the power registered is continually varying in the welding of bars of the same diameter. Another cause accounting to some extent for the different powers obtained with the same size of shafting is that the rheostat is not always worked from the same segment of the coils through the adding or deducting of the resistance, and consequently causes a greater or less excitation of the field of the alternator, thereby producing a greater or less electromotive force.

A Siemens electro-dynamometer was connected in series with the thick-wire coil of a Siemens watt-meter, the latter being in series with the primary coil of the electric welder. Connected across the terminals of the welder was the thin-wire coil of the watt-meter, in series with a non-inductive high resistance. A Siemens voltmeter for the measurement of alternating volts was also connected across the terminals of the welder. By this means the virtual volts and the virtual ampères were estimated with sufficient accuracy; and at the same moment a reading was taken from the watt-meter, giving the true watts absorbed in the transformer. At the time of taking the instrument readings, indicator diagrams were taken from the engine, which afford a considerable check on the results obtained from the watt-meter. In order to estimate accurately the power taken for each weld, it is necessary to add the power required to excite the alternator, and the power lost in transmission. For this purpose the resistance was measured of the mains supplying the current to the primary coil of the welder, and also the resistance of the mains carrying the exciting current; the former was 0·2 ohm, and the latter 2·6 ohms.

The electrical horse-power given in Table 1 (pages 328–9) is obtained from the true watts shown by the watt-meter, divided by 746, and the loss in the mains and in the exciting current is got by calculation; the loss in friction is the amount of power required to work engine, alternator, and exciter, at no load.

Strength of Welds.—The following particulars are taken from Mr. Fish's draft paper, and, owing to the care with which the work seems to have been done, may be depended upon as correct. He says:— " Twenty electric welds, bent hot, were bent through an average angle of 144 degrees before cracking, Table 2 (page 330). In cold-bending tests however the average with twenty pieces was only 66 degrees before failure of the weld occurred. As a cause for this comparatively early failure, Sir Frederick Bramwell suggests the extreme localization of heat in the electric welding process, and proposes annealing as a remedy. More recently a few welded bars, annealed either in the forge or by re-heating a length of five or six inches in the welding

machine immediately after the swaging and working of the weld was completed, have been tested by bending cold under the steam hammer. The results were much more favourable than those obtained by Mr. Kirkaldy, the average angle of bend at which failure occurred being about 130 degrees. In testing welds of smaller sizes, the writer has experienced but little difficulty in bending the bars, while cold, round their own diameter; and he suggests that in the Farnley welds failure in the bending tests was hastened by error in the method employed in making and finishing the weld, as well as by any possible effect due to the localization of heat.

"In testing Bessemer steel welds, Professor Kennedy obtained the following results:—

Diameter of bar	1·00	0·75	0·50 inch.
Average tensile strength of welded bar in percentage of unwelded . . .	92	97·5	100 per cent.

The decrease in efficiency of weld with increase in diameter would seem to be due to a proportionately smaller butting pressure during the welding. A high percentage of strength at the weld, 80 per cent. or upwards, and probably more than would be required in any practical test of the metal, can be obtained with most of the hardest steels. Most metals that are commercially pure, and certain alloys, weld with little loss of strength, except that which may be due to the annealing effect of the process; this loss may amount possibly to a total of 10 or 15 per cent.

"*Conductivity at Weld.*—Tests made by Professor Silvanus P. Thompson and others show that the electrical conductivity at the weld is practically the same as that of the unwelded material. This result is possibly an index of the soundness and homogeneity of the electric weld."

Conclusion.—The practical experiments made in the author's works show almost a better conclusion than the tests shown in published tables from the testing machine of the United States arsenal; for in bending cold here the weld has rarely given way.

continued on page 331.

TABLE 1.

Power expended in Electric Welding.

Work Welded.	1894.	Duration of Current.	Electrical Horse-power.				Indicated Horse-power.
			Watts/746	Loss in mains and in exciting.	Loss in friction.	Total.	
	May.	Seconds.	E.H.P.	E.H.P.	E.H.P.	E.H.P.	I.H.P.
2-inch Wrought-Iron Bar.	24	243	59	10·8	18	87·8	
Ditto polished all over.	25	256	55	10·8	18	83·8	
Ditto.	29	255	59	10·8	18	87·8	88
15-16ths inch Round Iron Bar.							
Average of 15 welds.	16	57	17·7	6·3	18	42	42
Average of 7 welds.	25	50	21	6·3	18	45·3	
1-inch Steam-Pipe, Wrought-Iron.	24	67	20·1	6·8	18	44·9	
Ditto.	24	66	19	6·8	18	43·8	
Ditto.	24	61	24·7	6·8	18	49·5	
Ditto.	29	86	15	6·8	18	39·8	49
Ditto.	29	66½	25·5	6·8	18	50·3	49

TABLE 1 *continued.*

Power expended in Electric Welding.

Work Welded.	1894.	Duration of Current.	Electrical Horse-power.				Indicated Horse-power.
			$\frac{\text{Watts}}{746}$	Loss in mains and in exciting.	Loss in friction.	Total.	
	May.	Seconds.	E.H.P.	E.H.P.	E.H.P.	E.H.P.	I.H.P
1-inch Bessemer Steel Shaft.	24	64	22·3	8	18	48·3	
Ditto.	24	65	22	8	18	48	
Ditto.	29	62	23	8	18	49	49
Ditto.	29	54	27·6	7	18	52·6	51
¾-inch Bessemer Steel.	24	37	15·5	6	18	39·5	36·5
Ditto.	24	38	15·2	6	18	39·2	36·5
Ditto.	29	50	17	6	18	41	48
Ditto.	29	54	15	6	18	39	43
½-inch Bessemer Steel.	24	21	9·2	4·7	18	31·9	
Ditto.	24	21	10·1	4·7	18	32·8	
Ditto.	24	36	8	4·7	18	30·7	
Ditto.	24	22	10·3	4·7	18	33	
Ditto.	29	25	9·2	4·7	18	31·9	
Ditto.	29	30	8	4·7	18	30·7	34

TABLE 2.

Bending Tests of Electric and Hand Welded Round $1\frac{1}{8}$-inch Bars of Farnley Iron.

Electric Welds were Butt. Hand Welds were Scarf.

Extracted from Messrs. Kirkaldy and Son's Report.

Welding.	Bent Cold.			Bent Hot.		
	Test No.	Angle of Bend.	Effect of Bending.	Test No.	Angle of Bend.	Effect of Bending.
ELECTRIC Welded.	Y			Y		
	404	37°	Broken	444	180°	* Cracked
	406	65°	Cracked	446	180°	Uncracked
	408	65°	Broken	448	160°	Cracked
	410	34°	Cracked	450	175°	Cracked
	412	58°	Broken	452	94°	Cracked
	414	115°	Broken	454	180°	Uncracked
	416	65°	Cracked	456	60°	Cracked
	418	57°	Cracked	458	180°	Uncracked
	420	37°	Broken	460	96°	Cracked
	422	58°	Broken	462	180°	Uncracked
	424	58°	Cracked	464	180°	† Cracked
	426	50°	Cracked	466	81°	Cracked
	428	90°	Cracked	468	163°	Cracked
	430	150°	Broken	470	98°	Cracked
	432	95°	Broken	472	180°	Cracked
	434	59°	Cracked	474	90°	Cracked
	436	70°	Cracked	476	120°	Cracked
	438	35°	Cracked	478	180°	Uncracked
	440	55°	Broken	480	180°	Cracked
	442	64°	Cracked	482	117°	Cracked
	Mean of 20	66°		Mean of 20	144°	
HAND Welded.	640	60°	Cracked	662	100°	Cracked
	642	180°	Uncracked	664	75°	Cracked
	644	90°	Cracked	666	180°	† Cracked
	646	150°	Cracked	668	180°	† Cracked
	648	170°	Cracked	670	180°	† Cracked
	650	75°	Cracked	672	180°	† Cracked
	652	180°	Cracked	674	180°	† Cracked
	654	180°	Uncracked	676	90°	Cracked
	656	180°	Cracked	678	180°	† Cracked
	658	180°	Cracked	680	180°	Uncracked
	660	70°	Cracked	682	95°	Cracked
	Mean of 11	138°		Mean of 11	147°	

* Very slightly cracked. † Slightly cracked.

But in explanation of this it must be borne in mind that all the piecings of plain bars are here more or less swaged. It is well within the mark to state that there is not one out of five hundred welds which turns out a failure or even defective.

The question of cost, which of course is of importance to commercial engineers, has not been alluded to in detail. The author admits however that the payment of royalty, the cost of horse-power, and the depreciation which on electrical apparatus is heavy, together bring the cost considerably over the net cost of the ordinary smith's hearth work, while the actual payments in wages and so on are considerably less. The loss in weight of iron is about one-twentieth only. It may be taken that on straightforward welds the total cost will be between 10 and 15 per cent. more than the ordinary smith's work; whereas in delicate work and difficult operations, such as have been alluded to, the cost will probably be one-third of the smith's work. But the real advantage of the apparatus, at any rate as at present arranged, is not so much an economy as a method of securing an absolutely reliable result, and occasionally saving considerable expenditure by its special adaptability.

Discussion.

Mr. Dobson exhibited a collection of samples illustrating the kind of welding that the machine was capable of doing with electric force. One was a sample of wrought-iron welded to german silver; others, zinc to block tin, lead to block tin, and steel to iron; another, copper to brass, which were about the most difficult metals to weld that he had yet come across in these trials. Another sample, showing the effect of piecing a tube in the machine, had been cut through obliquely across the weld with a view of showing the fibre

(Mr. Dobson.)
as plainly as possible, and also the amount of burr formed inside the tube by the pressure in welding. Unless the tube was a short length, so that a mandril could be got in to prevent the burr from forming, the burr was an inevitable result of welding by this or any other method; but it was found that the burr was smaller under electric welding than under the ordinary method of tube welding. Two specimens of welded bars of wrought-iron had been cut obliquely through the centre of the weld, and prepared with acid in order to show the curvature of the fibre under the pressure and the subsequent swaging. One peculiarity of these was that, in treating them with acid, the portion of the bar which had been underneath in the operation of piecing was everywhere eaten into more easily than the portion which had been uppermost; and he should be glad if some one who knew more about it would explain why this was so. Another sample was a piece of ordinary commercial bar-iron bent over cold on itself at the weld, showing that it had been bent completely without any signs of failure. Another specimen showed how a flat iron bar was squeezed up by the end pressure in the machine, and then a drift was driven through the enlarged part while still hot, to make a hole through it there; this was one of the things which could be made on the machine cheaper than by any other process. Another piece was a flat welded bar that had been pieced, and then twisted round at the weld to ascertain whether under such treatment there was any part of the bar that would show any sign of weakness; no sign of the kind however could be detected. It had not been found that any portion of the welded bars, whether flat or round, had any difference of strength—that one part was any weaker or stronger than another; the only peculiarity was the one he had alluded to, namely the differing effect of acid upon the fibre. A sample was shown of two pieces of boiler plate riveted together in the electric welding machine; it appeared to be a satisfactory piece of work. As could be well imagined from these examples, the machine lent itself to an almost endless variety of purposes. By this means it was possible to do things that could not be done in any other way; and he had no doubt that, as the plan came to be better understood and to receive a more general application, repair work on ships in difficult portions

of the hull, and other work of that kind, could be done with electricity in cases in which the repairing was now a most serious and expensive business. As he did not profess to have anything more himself than a superficial knowledge about electricity, Mr. Cockerill, who had been good enough to carry out the experiments for him and understood the matter thoroughly, would be glad to give any information upon technical questions that might be asked; while in regard to the mechanical parts of the subject he should himself be happy to answer any enquiries.

The President pointed out that, although in the present paper a particular plan of electric welding was described, the discussion was of course open to remarks on other plans, and also to any remarks from a general point of view as to the applicability of the plan to particular classes of work, which either could not be done so well or could not be done at all without its use.

Mr. Alfred Saxon had been much interested in smithy work for a number of years, and should hail any new method of welding from which he might be able to obtain the benefit of any advantage there might be in working it, although it might not displace entirely the old methods. The plan described in the paper was after all somewhat limited in its application to smithy work in a general engineer's workshop. It was stated, for example, that in the machine worked by the author bars of iron and steel had not yet been pieced of more than $2\frac{1}{4}$ inches diameter. In break-downs however and other work it was often necessary in an engineer's smithy to piece bars of iron and steel up to 4 and 5 inches diameter. It seemed to him that it would be less expensive to couple long shafts by couplings than to weld them by the method now described; in designing new work particularly, couplings might be introduced where bars of iron and steel could not be got of suitable length; but, owing to steel makers and iron manufacturers producing bars of greater length than formerly, there was not now so much difficulty in this direction as there had been in past times. It appeared to him that the mechanical power required for piecing large bars of iron or steel

(Mr. Alfred Saxon.)
would be enormous. If as much as 80 horse-power was required for welding a $2\frac{1}{4}$-inch bar (page 320), he should be glad to know what the author's idea was as to the horse-power that would be required for piecing a 5-inch or 6-inch bar.

In reference to good and bad welds and to the necessity of swaging, he could quite corroborate the experience of the author: swaging was undoubtedly an advantage. In addition to the examples given in page 325 of work done by electric welding, he believed that steel foundries were now using the electric welding process, presumably to improve the quality of the castings, or at any rate their appearance; and owing to the ability to weld together by electricity even different kinds of material, he imagined indeed that it sometimes occurred that cast-iron had been welded in with steel castings. Electric welding of large steel castings he thought must be of a very local character: in his opinion the process would not add to the strength of the casting, but might enable a casting slightly defective in appearance, yet with sufficient margin of strength, to be utilised, which would otherwise have to be rejected. He had himself had some experience of another kind of welding machine, which was worked by hand power; it was rather an inexpensive machine, and was capable of welding bars up to 5 inches diameter; it appeared to him to be useful in a general engineer's workshop, especially if it were improved as he considered it was capable of being. Perhaps the application of hydraulic pressure instead of hand power for forcing the pieces together in this machine would make welding even more safe for large bars than it was at present. But it seemed to him that it would be necessary to look in some other direction than that of electricity for the means of dealing with large bars: at any rate to engineers not possessing a large amount of capital such an array of machinery as had been described in the paper would be too serious an expense for a forge or for an ordinary smithy. None the less was he much obliged to the author for having taken so much trouble in making a thorough practical trial of electric welding, and for having shown by the results given in the paper that at any rate at present for an ordinary engineering workshop the plan was more a luxury than a necessity.

Mr. Thomas Cockerill said that, as to the chemical effect of the acid upon the iron on opposite sides of the weld (page 332), he was himself rather at a loss for an explanation of the difference observed between the upper and lower parts of the section of the welded bar. After the iron had been cut obliquely through the weld, it had been put into a solution containing 10 per cent. of sulphuric acid; and he thought that, as the two pieces of iron welded together had not been cut from the same bar but from different bars, the one might be slightly more positive than the other, and therefore in the solution an electric action might be set up between the two, with the result that the positive piece was more acted upon than the negative. This was only a theory of his, and it might be entirely wrong, as he had not yet been able to examine the matter sufficiently.

In respect to the measurements of the current which were given in the paper, all the instruments used had been accurately tested twice over, so as to make sure of their correctness. Besides this, the indicated horse-power had also been measured, which in almost every instance came out very near to the total electrical horse-power, after allowing for the loss in the mains and the loss in friction, as seen in Table 1 (pages 328–9). The electric welder he was confident could weld work of any magnitude, if only it was furnished with sufficient power. The piecing of a 5-inch or 6-inch shaft by electricity had been spoken of (page 334) as impracticable on account of the cost. The latter however he thought would be but little. For a 1-inch bar of Bessemer steel it was seen from Table 1 that only 27·6 electrical horse-power was required at the welder for 54 seconds; and to piece a 2-inch bar required only 59 electrical horse-power for 243 seconds. These were the figures apart from the loss of power in the main; and from Table 1 it was seen that there was a large loss on that account, in consequence of the electric welder being such a long way from the dynamo. With electric welding he considered any kind of work could be done, and when the time was taken into account the power was not excessive and the cost not disproportionate; nor could the process by any means be regarded as only a luxury.

Mr. C. FREWEN JENKIN, having had charge for a time of what he believed had been the first electric welder in England, namely the one used by Mr. Webb at Crewe, desired to congratulate the author on the success of the work he had turned out. The machine at Crewe had not always been found successful. It was an unadvisable arrangement, he thought, for an electric welder to be driven from a main shaft; but the author had succeeded in doing this. At Crewe it had certainly produced great variations in speed, and the speed of the rest of the machinery in the shop audibly pulsated down and up as the welder worked. The power of course came on for a few seconds only, but during those few seconds it was very great.

With regard to the projection of the bars beyond the clamps in the welding machine, he thought there must be some mistake in the statement in page 323; surely the larger bars would project further than the smaller. In page 324 it was stated that no preparation of the surfaces to be joined was necessary; but with ordinary iron, at any rate when it was dirty or when there was any scale on it, he thought it was necessary to file up the surfaces that were in contact with the clamps, so as to get the rough scale off. All the ordinary kinds of welding had been successfully carried out at Crewe; but the main object for which the electric welder had been obtained had been for the welding of boiler tubes, and for this purpose it had been unsuccessful. In Figs. 13 and 14, Plate 84, were shown the ordinary ways in which tubes were welded. For boiler-tube welding it had been found that the butt joint shown in Fig. 13 was useless. The ends had to be prepared, so as to make the lap joint shown in Fig. 14; and even then, as far as he remembered, about 7 per cent. of the tubes so welded had minute pin-hole leaks. The tubes were of steel, and their ends had to a certain extent been burnt, from having been used in locomotive boilers; and when new ends were pieced on by electric welding, it was found impossible to avoid the pin-holes at the weld, which were sufficient to let the water leak through. The joints themselves stood hydraulic pressure, but the water oozed through these minute leaks; and the plan had been abandoned for that reason. The difficulty of the burr inside had been got over by suitably shaping the ends of the tubes, and after they had been

welded swaging them on a central mandril, which was pushed into the end after the tube had been taken out of the clamps.

The great difficulty in ascertaining the power required for working an electric welder lay, he considered, in estimating correctly the time occupied. A continuous recorder he suggested should be put on the steam engine, by which the indicated horse-power could be added up continuously. Having himself used such an indicator on a rolling mill, he thought if it were put on the engine employed for electric welding it would give an accurate record of the total horse-power indicated for each weld. The record given in page 331 of the percentage of failures was remarkable, not one out of five hundred welds having been defective. At Crewe, where there had not been at that time so much experience as the author had now had, the failures were certainly more numerous.

Mr. Edgar Worthington said the author was certainly to be congratulated on having such a large percentage of successes in the welds he had made. It appeared to him that finishing the welds by swaging was to a large extent the cause of the great proportion of successes. In irregularly shaped parts which were sometimes welded by electricity, he thought it was not possible to swage after the welding had been performed : in which case the pressing together of the two parts in welding was entirely done either by a screw, as shown in Fig. 4, Plate 81, or in larger pieces by hydraulic pressure. With regard to size, it was unfortunate for the information of the members that the author's experience in electric welding was limited to pieces not exceeding $2\frac{1}{4}$ inches diameter. It had been his own good fortune to witness in the United States electric welding of much larger sections ; and although he was not able to give the horse-power absorbed, it might be interesting to mention that sections of 9 square inches were welded about every ten minutes in making the steel crossings for electric street railways. That was done in order to avoid so many irregular and complicated fish-plates in making the crossings of the electric railways so much used in that country. The machines used for that purpose were really treble machines. One was a large welder, carried in a crane, and deposited on the top

(Mr. Edgar Worthington.)
of the deep rails to be welded; then a horizontal machine on each side was brought forward into contact with the rail surfaces, which were rendered clean by a dry emery wheel so as to ensure complete contact of the poles. The three welding machines were all under the control of one man, who increased or diminished their power according to the shape and thickness of the section which they were heating. Hydraulic pressure was brought to bear upon the work by a second man; and a third man was in readiness for odd work. While one rail of 92 lbs. per lineal yard was being welded, which occupied a space of six minutes during the heat application, other similar sections or other pieces of work were being prepared upon temporary platforms; so that, as soon as one weld was completed, another was ready to bring round to the welding machine. That seemed to him to be the principle of the commercial success of electric welding, because, as pointed out by the author, an expensive plant was necessary for providing the large amount of power which was required for perhaps only a few seconds at a time, thereby rendering the work very costly; it was therefore only by frequent application of the power that economy could be obtained. Of other methods of electric welding, the use of an electric arc for the purpose had been carried out—perhaps in some instances, as had been suggested (page 334), for improper purposes—but also successfully for ordinary and proper commercial purposes. The arc arrangement consisted of a carbon point, something like that of an arc light, which was held in the hand by an ordinary wooden handle, and was screened from the face of the operator by a large semi-opaque disc, through which he could see the point of the arc; he had also to wear glasses, because of the dazzling light from the arc point. The work itself formed the other pole. In the working the operator had four powers under his control, that is, he could bring one, two, three, or four measures of current to bear upon the work. This method was used chiefly for local welding, and really entailed the melting of the metal. It was also useful for welding small articles which did not require much pressure to be brought to bear upon them, or which did not require much hammering. When he saw the arc welding at work, one of the processes happened to involve its use in the place of a drilling and

slotting machine. The operation was to cut a recess in an iron casting; and instead of cutting this out by drilling and slotting, it was burned away by the pole of the arc.

Mr. Henry Webb wished to corroborate what had been said in the paper as to the quality of the work done by the welding machine at the author's works. He had had frequent opportunities of seeing it in operation there, and had been astonished at the splendid work turned out. He had seen all kinds of sections operated upon, and as far as he could observe the result was simply perfect. The ease of the work and the shortness of the time in which it was accomplished were exceedingly remarkable. He had early come to the conclusion that one condition required for successful working was continuous working, best expressed by the word "legion." Where the machine could work 500 welds of one kind and 500 of another, following on one after the other, there electric welding was simply perfect; but, as pointed out by Mr. Saxon (page 334), if the electric welder had to go into a jobbing shop, and after being used for one kind of work had to be changed every few minutes for another kind, he thought it had better not be adopted.

Mr. Jeremiah Head, Past-President, questioned whether the term electric welding was not somewhat of a misnomer, and whether the operation ought not rather to be called electric fusion. What he had hitherto been accustomed to regard as welding had consisted in taking advantage of the property which iron and some other metals possessed of becoming plastic at a temperature somewhat short of fusion: when, if the surfaces were perfectly clean and brought together with some pressure, they would adhere and become homogeneous. In the present case it was clear from the specimens exhibited that metals which were dissimilar could be brought together and united. But it seemed scarcely conceivable that wrought-iron and cast-iron, for example, which were here shown to be united, were welded in the ordinary meaning of the term; it appeared to him to be more in the nature of a fusion of the two materials. And not only so, but when the smith brought two

(Mr. Jeremiah Head.)

pieces of iron together and heated them to a welding heat, he knew that in transferring them from the fire to the anvil the oxygen of the air united with the iron at that temperature, and formed a scale, which was the almost infusible magnetic oxide of iron. Before he welded the pieces he threw on them certain fluxes, sand for example, which uniting with the magnetic oxide formed a silicate or fusible slag. He thereby got the two surfaces perfectly clean, and they would unite properly. In page 325 of the paper it was mentioned that the dirt, scale, or oxide made its way to the outside; but nothing was said about using any fluxes to assist, as was done in the ordinary welding process. There were some kinds of iron which were exceedingly difficult to weld; and the curious thing was that the purer and better, or, as the forgemen said, the drier the iron was, so much the more difficult was it to weld, because it did not contain any of that silicate of iron which enabled the surfaces to be kept perfectly clean when they were brought together. From the trials of the electric welding process at the Crewe Works the opinion had already been expressed by Mr. Jenkin (page 336) that the rough scale ought to be filed off the surfaces of ordinary smithed iron before they were brought together in the electric welder. This seemed to point to the absence of the use of any flux; yet how the author managed to do without it, if he did do without it, he himself could not understand. His idea that there was actual fusion of the metal at the uniting surfaces seemed to be confirmed by the experience of what had been alluded to (page 338) as an improper use of the electric current, namely for filling up blow-holes in steel castings and for similar purposes. That this was an improper use he did not indeed admit; in fact it seemed to him to be a necessary, desirable, and proper use of electricity. Having several times watched this use, proper or improper, he had noticed that absolute fusion seemed to take place. It certainly seemed to him a meritorious thing by this means to convert a casting which was spoiled by a few blow-holes into a good sound casting fit for use; it was quite a different procedure from employing putty or anything of that kind to patch up the appearance of defective work. One description of work to which he

had seen electric welding applied he regarded as more difficult than anything which had yet been mentioned, namely the welding of the seams of steel casks for carrying petroleum. These casks were made of thin steel plates, not more than 1-16th inch thick; such casks were being made at the Bowling works at present. By electric welding they were now made without any riveting whatever; a seam as long as 2½ feet of these two thin plates was welded together so as to be perfectly tight; and if it would stand the searching nature of petroleum, it would not let anything else get through. The ends were also welded all round by means of an arc welding apparatus. The casks were afterwards tested, and proved to be tight before they were sent out; they were now being manufactured he believed on a commercial scale.

Mr. Thomas Clarkson asked whether there was any difference of procedure in the welding of rings, like that shown in Plate 80, which seemed to be a different kind of work from any of the others mentioned. If the ring were much shorter than the hoop here illustrated, it seemed to him that there might be some difference in the result; a shorter ring he imagined might take a longer time to weld. One great advantage of the plan appeared to be that the result was independent of the previous condition of the surfaces; in the very process of welding they became beautifully clean. By means of electricity he had seen bars one inch square of a highly complex alloy effectually welded together; the alloy contained manganese, copper, zinc, tin, and several other elements, and the flux used was simply borax; the welding was done in the way described in the paper, and was a very good job. That electric welding was really performed by actual fusion of the metal, as urged by Mr. Head (page 339), could be readily seen by watching the process now adopted for welding copper telegraph wires automatically by electricity: the two ends were pressed together by a spring, and immediately that the metal was softened the spring pulled them closer together, and at the same time broke the circuit and cut off the current. It was done so smartly that there was only just time to see the copper fused, and almost instantly a little drop

(Mr. Thomas Clarkson.)
of melted copper remained suspended from the point of union. This he thought was an advance that was rather novel in welding.

Mr. JAMES PLATT, Member of Council, wished to corroborate the author's experience. At the Gloucester Railway Carriage and Wagon Works the Thomson-Houston electric welder had been used, and it answered the purpose very much in the way described in the paper. The pieces to be welded did not require any preparation of their ends. Just as they came from the shears or the saw they were put into the welding machine and welded together. With regard to the cost, it was not commercially a paying process at present, but it would do the work soundly and satisfactorily. With reference to arc welding, apparatus of that kind had also been put up, but it did not answer the purpose for which it was intended, though for some purposes it did exceedingly well. Some of the larger steel works used it for other purposes besides "faking up" steel castings; they used it for heating and thereby softening hardened steel-faced armour plates at the particular places where the holes for the bolts had to be drilled; the holes could then be drilled with ease; this was an excellent practical application of the plan. Another purpose for which the arc welding machine proved highly useful was the flanging of a large number of plates, 3-16ths inch thick and of considerable width, on which a narrow flange was required all round the edge. Instead of being put into the plate-heating furnace, they were put on a block and raised to the required heat by the electric arc, and the flanging was done well and satisfactorily. There were many other applications for electric welding; but up to the present time the power required and the wear and tear of the apparatus were too great for economical working.

Mr. CHARLES COCHRANE, Past-President, noticed that from a perusal of Table 1 in the paper an important question arose as to the power required with an increase in the area of the section to be welded. It appeared that with a 1-inch bar only 23 electrical horse-power was required (page 329). Reckoning according to the sectional area, a 2-inch bar ought to require four times as much, or

92 horse-power: instead of which it was seen that only 59 horse-power was required (page 328). In the American practice of rail welding, mentioned by Mr. Worthington (page 337), the area of 9 square inches would be equal to a bar of $3\frac{3}{8}$ inches diameter; and if the amount could be stated of the horse-power needed, it would help to a clearer understanding of the encouragement to be derived from increase in the sectional area to be dealt with, and the proportionately less power that would be required to accomplish the welding.

Mr. Ralph H. Tweddell considered mechanical engineers were greatly indebted to the author for the account he had given of the results of his apparently somewhat expensive experiment in electric welding, in regard to which it would be interesting to have some further information upon one or two points. As to the power applied by the handwheel for bringing the two ends of the bars together, apart from the horse-power required to produce fusion, the machine shown in Plate 81 seemed to have little more power than a letter-copying press. Where the two surfaces had been brought together by this handwheel, there appeared again to be a great divergence of opinion as to the horse-power actually required for producing fusion. In a paper read some time ago by Mr. Frederick P. Royce at Chicago, before the Buffalo Convention of the Carriage Builders' National Association, the horse-powers differed considerably from those given in the present paper. For 2-inch round bar-iron Mr. Royce gave 75 horse-power through 95 seconds. For the same size Mr. Dobson in Table 1 gave 88 indicated horse-power through 255 seconds: or three to one, taking the product of the power multiplied by the time. For 1-inch bars Mr. Royce gave 25 horse-power for 45 seconds; and for 15-16ths inch bars Mr. Dobson gave 42 horse-power for 57 seconds, or two to one. It might possibly be however—though he had not had an opportunity of ascertaining whether it was so—that Mr. Royce's figures meant electrical horse-power at the welding machine: in which case the comparison would be, for 2-inch round bar-iron about two to one, instead of three to one; and for 1-inch bars about equal in the two examples. There was also a considerable difference in regard to the power required to weld steel and iron. According to

(Mr. Ralph H. Tweddell.)

the present paper an inch steel bar required $49 \times 62 = 3038$, as against $42 \times 57 = 2394$ for 15-16ths inch iron, being about a quarter as much again for steel; or about 10 per cent. more for steel if the sectional area were the same. Sir Frederick Bramwell had given 50 horse-power through 68 seconds for bars $1\frac{1}{8}$ inch diameter of Farnley iron (Proceedings Inst. C.E., 1890, vol. cii, page 25), which was again a different amount, the product being 3400, equivalent to 2686 for 1-inch bars. These were large amounts of power, and it was important to know which was correct. Among the specimens shown by the author was a small forging like an eye-bolt with a hole through the middle, which he assumed must have taken 50 horse-power to make it; but he was sure it could be done with say a horse-power by hydraulic pressure with the greatest ease. From another specimen it seemed that after all there was still some riveting to be done, notwithstanding all the improvements in welding joints by electricity; and curious riveting it looked, according to the representation given in Figs. 17 and 18, Plate 84, about which there was a vagueness in regard to the pressure applied that occasioned him great perplexity. If the pressure to close the rivet was no greater than that given by a letter-copying press, the result he thought must be a rather poor illustration of riveted work. But why attempt to use the electric welder at all for heating rivets? Many hundred 1-inch rivets could be heated in a day by a small boy with an oil furnace at the cost of a few pence; but it seemed to take 25 horse-power through 45 seconds to heat one 1-inch bar. Some experiments in which he was much interested had been made for caulking by the Benardos process, running an electric arc along the plate edge and causing fusion of the metal. It had not been carried out yet to any definite success; but there seemed a considerable scope for it. Its success seemed really more a question of heating than anything else; it was the best mode that he knew of heating up work, and doing so in a convenient manner. Between a smith's forge and an engine developing 50 horse-power for welding a $1\frac{1}{8}$-inch bar there was certainly an enormous difference in the first cost. In Sir Frederick Bramwell's paper it was mentioned that at that time, when the invention was first brought over from America, forty-four

welds of $1\frac{1}{8}$-inch round bars were made by hand by two men in three hours with $1\frac{1}{2}$ cwt. of coke; while in the same length of time eighty welds were made by the electric welder worked by an engine developing 50 indicated horse-power, and nevertheless doing not even twice as much as was done by the manual labour of two men. The invention no doubt had its uses, but certainly he did not see that it was at all likely to supersede generally welding for example by the hydraulic press. It had been said that a 5-inch bar could be welded by a machine worked by hand-power (page 334). If a man could weld a 5-inch bar by hand-power, which however seemed impossible, surely such an enormous horse-power as had been mentioned for the electric welder was a great expenditure to attain the same end. Possibly there was a great future for the invention; but it must be used under special conditions, and only for an enormous amount of similar work, involving few settings and adjustments. Eventually it might lead up to the total abolition of riveting, which would be a good thing in many ways, and a bad thing in others. For putting together any difficult structure like a ship, why not bring this process to bear in the same way that had been described by Mr. Head for welding petroleum casks? namely by fusing the plates together along the side of the ship, instead of riveting the joints as in Fig. 18, Plate 84.

Mr. John A. F. Aspinall, Member of Council, said that the identical welding machines which the author had done so well with had been tried by himself for a time at the Horwich locomotive works of the Lancashire and Yorkshire Railway. He had had them at work for three or four months, and his experience had been very like that of Mr. Dobson to start with, when he expected to be able to do with about 30 horse-power what he found actually required 80. After having gone into the matter carefully, and having done a considerable amount of work, both with solid bars and with tubes, he had not found that any work could really be done commercially with it, and he had had to give it up. It had been found to be more expensive than doing work by hand. While it would have suited possibly for finished work—for bright work such as the author

(Mr. John A. F. Aspinall.)
had spoken of, where iron or steel could be heated locally, doing but little damage to the work—he had himself so little work of that kind that it was not worth while to adopt it. Of locomotive tubes, which was the one thing he had hoped the machine would be well adapted for, a large number had been welded by it, and he had not experienced the difficulty spoken of by Mr. Jenkin (page 336); whether it was that the material of the tubes was different he did not know, but all those which had been welded were tested afterwards by hydraulic pressure in the ordinary way, and were found to be sound. One point of great importance about the machine did not seem to have been mentioned, namely that it was adapted only for holding perfectly straight work. As shown in the drawings there were two clamps, intended for bringing two pieces of straight work together; but when irregularly shaped pieces had to be welded, the machine would be practically useless. He had indeed wondered why those interested in the machine had not taken greater trouble to develop the methods of holding the work, so as to adapt the machine for doing general work, instead of leaving it absolutely in its original form. An electric welding apparatus brought to this country from America and exhibited in Birmingham for a short time by Mr. Burton had struck him as having admirable appliances for holding work of all sorts; but he had heard little of it. With regard to the Benardos plan of arc welding, he had been told of its being successfully used for cutting a defective piece out of a boiler and then welding in a fresh piece in its place in the interval between leaving off work on Saturday and starting again on Monday morning. He saw no reason why the plan should not be used for castings which might have some defect in them. If a casting of any kind had a blow-hole in it which was visible, why should it not be filled up with metal of the same character, melted by the Benardos process and welded into the casting itself. Though he had not yet done anything in that way himself, he had seen samples of that kind of work, and certainly to all appearance the work was quite as good as if no blow-holes had existed.

Professor W. H. Watkinson, referring to the statement in page 331 of the paper—that the payment of royalty, the cost of horse-power,

and the depreciation which on electrical apparatus was heavy, together brought the cost of electric welding considerably over the net cost of the ordinary smith's hearth work—believed it was possible to arrange apparatus which would be much cheaper, free from royalty, and practically not subject to depreciation. The cost of the machinery used by the author was about £700, including the engine. The cost of the welding apparatus might be reduced to about £100, and the cost for horse-power might be reduced by 70 or 80 per cent. What was called electric welding was really electro-fusion, as had been pointed out by Mr. Head (page 339). It was interesting to note that the first person to draw attention to this subject had been the late Dr. Joule; but Lord Kelvin (then Professor Thomson) had been the first to make the experiment. It was in 1856 that Dr. Joule had read a paper on the "Fusion of Metals by Voltaic Electricity" (Memoirs of the Literary and Philosophical Society of Manchester, 1856, vol. 14, page 50; and Scientific Papers of James Prescott Joule, page 381). Dr. Joule had also been the first, as far as he had been able to ascertain, to adopt the electric method of hardening, and had employed it before 1865. A list was given in page 325 of metals and different kinds of work that had been welded by the author; and Dr. Joule had actually made experiments and had succeeded in fusing a small bundle of steel wires into one, uniting steel with brass, platinum with iron, and so on. Whence it would seem that it was open to any one to fuse or weld metals together by electricity, so long as reliance was placed simply on the weight of the pieces themselves for pressing them together. If therefore the bars to be welded together were placed upright, one resting on the other, the weight of the upper bar might be arranged to give sufficient pressure for welding, without having recourse to the assistance of the screw contrivance shown in the drawings for pressing the horizontal bars together. In welding by the Elihu Thomson or incandescent method, what was required was a large current of 10,000 to 40,000 ampères at a low pressure of only 1 or 2 volts, the quantity depending on the metals to be welded and their sectional area. In the arrangement used by the author this large current was obtained by the use of a transformer. A small

(Professor W H. Watkinson.)
current of 30 to 130 ampères was generated in an alternator at a high pressure of about 300 volts, and was then transformed into the large current at the low pressure by a transformer; and the quantity of the current supplied to the welding machine was regulated by the reactive coil. Altogether therefore the apparatus employed was too complicated for most workmen, and seemed easily capable of getting out of order, besides being expensive. If instead of that method being adopted a dynamo were used to give a large current direct, and if the welding table were put upon the dynamo, all the difficulties of conducting so large a current to where it was wanted would be got over, so long as only one or two welding tables were required. Most works would not require more than one or two; and for the few exceptional cases where more welders were wanted the arrangement described in the paper was probably the best, because a large number of welders could here be worked from the same alternator, and wires be laid down to the different places where the welders were required. The arrangement which he suggested would consist simply of a dynamo to give a large current at a low pressure, belt-driven from the shop shafting, like any other machine-tool, and having a fly-wheel on the armature shaft. By using a fly-wheel having a rolled steel rim, it would be quite safe to run it with a rim velocity of 300 feet per second. With a fly-wheel 6 feet diameter this would correspond with 1,000 revolutions per minute; and if the rim weighed $5\frac{1}{4}$ tons, an amount of energy equal to 100 horse-power-minutes could be stored and re-stored with a fluctuation of speed of only 10 per cent.; by doubling the weight of the rim the fluctuation of speed would be only slightly over 5 per cent. The cost of the energy would be reduced by 70 or 80 per cent., because it would be obtained from the main engines working under fairly economical conditions, instead of from a separate non-condensing engine working intermittently and therefore inefficiently. One of the simplest dynamos, which he thought would commend itself to engineers, was an iron-clad dynamo by Professor Forbes, which might without damage be turned upside down, and could be safely put into the hands of any workman who could use an anvil. The armature consisted of a soft iron cylinder, and was enclosed in an iron casing.

By varying the current in the field-magnets the welding could be started with the low current necessary, and the strength of the current could be gradually increased up to the maximum for the finish.

Dr. JOHN HOPKINSON, Member of Council, thought it might perhaps be useful to point out, with regard to the increase of electrical resistance in iron and other metals with increase of temperature, that the behaviour of iron in this respect was a little peculiar. In most metals the electrical resistance increased with considerable uniformity as the temperature rose; but it was not so with iron, where the curve of increase of resistance with temperature was somewhat of the form sketched in Fig. 19, Plate 84. At first the electrical resistance in iron began to increase with the temperature much at the same rate as in copper or other pure metals; but as the temperature rose the rate of increase in the resistance increased, and went on increasing until a temperature was reached of 750° to 900° centigrade or 1,400° to 1,650° Fahr. Then the rate of increase suddenly changed; it diminished considerably, and the curve went on more nearly in a straight line. The temperature at the point of sudden change was the same as that at which the iron ceased to be magnetic; and it might be said broadly that it was the temperature at which the phenomenon of recalescence occurred.

The increased resistance of conductors with an alternating current was of course a matter that was now pretty familiar to electricians; but it might not be quite so familiar to mechanical engineers who were working out the practical applications of electricity to their own operations. The fact was that, with a large alternating current and a large conductor, the current was not uniform throughout the section of the conductor, but was in a large measure confined to the outer portions of the conductor, owing to certain magnetic principles into which he need not enter. The consequence was that, if the frequency of alternation was at all high, it could not be assumed that with a large conductor anything like a proportionate reduction of resistance would be gained. The actual result almost approximated to the old-fashioned notion of conductors conducting along their surface and not through their substance: a

(Dr. John Hopkinson.)
notion that was entirely erroneous with regard to continuous currents, but had a considerable element of truth if the currents were temporary or alternating.

The method of welding described in the paper had been spoken of as a luxury (page 334). It should be borne in mind however that in engineering progress the luxuries of today became the necessities of tomorrow.

Mr. THOMAS PARKER said it appeared to him that what the electric welder wanted was a father; it had been introduced into this country in a manner which had not tended to its general adoption. If its employment were required by mechanical engineers, electricians could greatly help forwards its practical utility. Up to the present time he agreed that the process was too cumbrous. As to the suggestion of reducing the horse-power by storing it in a fly-wheel heavy enough to allow only 10 per cent. fluctuation in speed (page 348), he considered a fluctuation of as much as 20 or 25 per cent. could easily be conceded, whereby the weight and cost of the apparatus might be much reduced. In the use of a large dynamo however he did not agree. A transformer with alternating currents he thought was the best, rather than a large current produced direct by a dynamo; it would be more handy, and would enable the mechanical power to be used to better advantage.

The condition of the welds, as to whether they were made by welding or by fusing (page 339), would depend largely upon the operator, and upon the time in which the weld was made, and upon the shape of the ends that were brought together, and upon the power available. No doubt a higher temperature might be made use of in the electric welder than in ordinary welding. The means employed for pressing the ends together would play a part in determining whether the welding was done while the metal was simply in a plastic state, or whether the temperature was raised sufficiently to melt the metal over the whole or any part of the junction. The chemistry of the process seemed to him not to have been sufficiently considered. If there were oxide or other elements on the ends of the pieces at the time they were brought together, there would

result a chemical condition which would seriously affect the character of the weld. The length of time occupied in making the weld would also have an important effect upon its character, by determining whether the metal would assume a crystalline or a fibrous condition. Electric welding was a highly important process, and electricians were looking forwards to seeing it generally adopted, for they believed that engineers could not do with a fire what could be done by the use of electricity applied to welding in the manner described in the paper; and he was sorry to hear the confessions of temporary dissatisfaction at Crewe and at Horwich. At the Smoke Abatement Exhibition in 1881 it would be remembered that Sir William Siemens had shown practically what could be done by electricity in the fusing and welding of steel and platinum, almost in the same manner as had been described in the present paper. Being himself anxious to see the process developed, he should be glad to render whatever assistance he could with that view, for he was sure that mechanical engineers generally had not yet grasped the great advantage which the method might be to them.

Mr. Charles Hopkinson asked whether in welding hard steel it had been found that the temper was affected by the local heating. Also whether any experiments had been made as to the resistance of the gap of continuity between the two pieces of metal: whether there was any definite point below which the resistance of the gap ought not to fall, in order to obtain the proper welding effect.

Mr. Dobson was gratified to notice the interest that had been taken in the paper so far as it went, and also to find there seemed to be a general belief that it was quite possible to further the process of electric welding, so as to make it more practical and economical. Perhaps the result of the present discussion might be to call attention to the subject as one eminently within the grasp of electrical and mechanical engineers; and possibly the manufacturing trades of the country might benefit to some degree thereby.

The fact that at his own works bars only of $2\frac{1}{4}$ inches diameter had been welded (page 333) was due simply to the size and power of

(Mr. Dobson.)
the particular machine there employed, and had nothing to do with the principle involved. It was possible to make a machine that should be capable of welding a 12-inch shaft as easily as the present machine welded a 2-inch shaft. As to introducing couplings in the design of new shafting, so as to avoid having to make long lengths by welding, he fancied that most of the line shafts in engineering workshops had couplings on them somewhere; and in making their designs engineers commonly took great care not to introduce lengths that would be at all unmanageable.

In explanation of the reason why the trials at Crewe had unfortunately not resulted in the success that had now been realized at his own works (page 336), he could only suggest that at that time the machine had only just come from America and had not got acclimatized; or possibly a mistake might have been made there, which had at first been made at his own works, in believing that mere fusion of the metal was sufficient for welding, as opposed to the mechanical work put into it in ordinary welding. The idea originally presented to himself in connection with the electric welder had been that a mere contact and the pressing of the two lengths of metal together were sufficient to form a weld. It had been found however that, although they would stick together for a certain time, the junction would not stand any strain; and that with a metal like iron, unless there was a certain amount of swaging, the weld was more likely to be imperfect than to be perfect. With other metals it was not so; they would not stand swaging. But for iron and for some of the lower qualities of steel, swaging was an absolute necessity. This was the only reason he could suggest why the experiments at Crewe had not proved satisfactory. The fact that the action of the electric welder produced a perceptible pulsation in the working of the rest of the machinery in the same shop proved only that there was not sufficient power to work the welder. Under the same circumstances at first he had also experienced the same result, and the welds had occasionally been imperfect; but since there had been a sufficiency of power he could state positively that in regard to quality of work there was no exception to be taken to it.

The special adaptation of the principle of heating by electricity for the purpose of welding together steel crossings for electric railways and tramways (page 337) served to illustrate one of the very points which he had wished to bring out in preparing the paper, namely that in regard to adaptability there was absolutely no limit to the range of electric heating. The illustration furnished by Mr. Worthington was one of the most difficult operations with regard to heating and welding, and he had testified to its being successfully and practically carried out.

In regard to the question of welding or fusing, to which attention had been called by Mr. Head (page 339), he had endeavoured to show in the paper that so far as the heating alone was concerned it was a process of fusion, but that for the work itself it ought still to be welding. Whether the heat was developed by electricity or by any other means, it was evident that a certain amount of fusion must be effected in the material before it could be welded. The mistakes that had originally been made in electric welding had arisen from the erroneous idea that iron could be welded by simple pressure. This he altogether denied. The fibre of the iron would not arrange itself properly at the weld unless there was some swaging. The process of arc welding as applied to thin steel casks for petroleum, which Mr. Head had mentioned witnessing (page 341), he had not yet had the pleasure of seeing himself; but others who had seen it had spoken of it as a most beautiful operation; he had been told the fusion was so immediate that it simply appeared as if the joints were being painted together.

The welding of hoops and rings, Plate 80, about which Mr. Clarkson had enquired (page 341), had seemed to himself also a difficult thing to understand. When there was a continuous conductor from one pole to the other through the unbroken portion of the ring, why should the electricity take the trouble to go the shortest and most difficult way where the gap offered the greatest resistance? It had been found by Mr. Cockerill, who had examined into it, that this was simply owing to the fact that there was a self-induction through the alternating current in the unbroken portion of the ring which connected the poles; and that the

(Mr. Dobson.)
greater length of this portion allowed it to keep cool, while the shorter portion in which the break occurred became hot. If a ring of much smaller diameter, say 6 inches, were placed in the clamps, the heat would spread also through the unbroken portion, and would gradually come to the middle point opposite to the gap, by the time the fusion was completed at the gap.

With regard to the horse-power required for welding different sizes of work, to which Mr. Cochrane had alluded (page 342), it was a fact that in all sizes there was a considerable amount of loss from the resistance in the lead, and from the friction and the leakage, and from other causes of loss which it was customary to meet with in the practical employment of mechanical power. It must also be evident that the loss would be proportionately greater in smaller sizes of work than it would be in larger; and therefore if it were required at any time to construct a welding apparatus for larger sizes, the probability was it would be found that, the larger the surface to be welded, the less would be the horse-power required per square inch of surface. When it came to piecing such large diameters as had been spoken of, he was convinced it would be found that, as a means of producing the required heat, electricity was much more controllable and much more easily directed than any other method of heating: besides having the advantage that it localized the heat to such an extent that the other portions of the work were not affected, and could be easily handled, remaining practically cool.

The riveting done by the electric welder had been humorously commented upon by Mr. Tweddell (page 344), as though this method were going to come into competition with hydraulic riveting machines. It seemed hardly necessary to assure him however that the electric riveting, of which a specimen was shown, was not intended to compete with hydraulic riveting; but was simply to show that this also was a species of work which could be done by the electric welder, without raising the question whether it could be so done advantageously or not. If he had himself any riveting to do, he should certainly stick to the hydraulic riveting machine, for the present at any rate.

The hand-wheel for pressing together the two ends to be welded was on the head of a screw actuating the sliding clamp, Plates 79 and 80, much like the arrangement in a letter-copying press (page 343). The pressure found necessary for welding bars of $2\frac{1}{4}$ inches diameter did not require any strain on the man's arms for bringing the ends together sufficiently to stick them together; it would be equivalent he thought to about the pressure put upon a copying press.

Although Mr. Aspinall, who had given this subject a great deal of attention, and had had these identical machines under his control at Horwich (page 345) before they came to Bolton, had been less fortunate in his experience, it would be clearly gathered from what he had said that his objection to electric welding was on the score of cost, and not on the score of practicability. The question of cost he admitted was at present an obstacle to the general adoption of the process. At his own works it had not proved an obstacle, because for the reasons mentioned in the paper he considered he had been amply recompensed for the expense incurred; indeed the satisfaction of knowing that the work was absolutely sound must itself count for something, even if it cost a little more.

For the purpose of welding he had heard of other attempts lately to heat by electricity; and he had tried hard to see a process of which glowing accounts had appeared recently, namely heating under water, or rather using water as one of the mediums for causing the resistance necessary to induce heating. The bar to be heated was one electrode, and the water contained in a sort of bath having a metallic lining served as the other electrode. The idea was that, on passing the current through, the resistance of the water would produce around the bar a sort of vacuum, which formed the best resistance possible because there was nothing to conduct the heat away; and therefore the iron plunged in the water would become heated. As a matter of fact it did so. It was also suggested that there was a chemical action in the decomposition of the water, which supplied oxygen to increase the heat; this might or might not be the case. In spite of every endeavour he had been unable to get to see it; and he had afterwards learned that the reason why it had not been shown

(Mr. Dobson.)
to him was that it was not considered satisfactory on account of the enormous amount of horse-power that it took. If it took more than the present machine at his own works, it was evident that in this simple apparatus, which constituted one of the most simple applications of electricity, the question of horse-power had still to be considered. [See page 358.]

In welding tempered steel (page 351) the effect of the welding was that the temper was destroyed. At his own works it was the constant practice when the tools had been worn down—such as the planing-machine tools and other expensive tools—to weld them together one after another in the electric welder; and as the bars so made were allowed to cool gradually, the temper of course went. But he was glad to say that the operation of welding did not put the slightest difficulty in the way of re-tempering the steel; the tempering was done as easily and as certainly all through the built-up bar as it had been done originally in the several pieces.

As regarded a minimum resistance in the break of continuity at the gap in the welder (page 351), and the opinion that it was necessary for the ends of the bars to be filed up so as to be clean and to come pretty close together, the latter was entirely contrary to his own practice. Whether the bars were sawn or sheared, he had found the result of the first contact to be that all the small points first touching were immediately obliterated by fusion. As the surfaces came closer and closer together, the area of resistance began to increase, and the metal was fused over a greater and greater extent, until it ended by the bar having an equal temperature throughout the entire area of its cross section. There was no minimum point where the resistance was least, except in the sense that the heating was commenced with the current weaker than was required to finish the piecing; the current was turned on gradually, and therefore the resistance was naturally less at first.

After having taken a certain amount of trouble in working out this process of electric welding to a successful issue, it was highly satisfactory to him to know that, whatever might be the results elsewhere, his labours had not been entirely lost.

The PRESIDENT said that in the winter of 1889–90 he had had the pleasure of spending some weeks in the United States, and of examining the process which had now been carried out so successfully by Mr. Dobson. He had been greatly pleased with the process, and with the apparatus which had been devised in America for carrying it out. Having given a number of notes of his experience in the matter to the Institution of Civil Engineers (Proceedings 1890, vol. cii, page 52) in the discussion upon Sir Frederick Bramwell's paper, he need not repeat them here.

The members he was sure would wish to pass a hearty vote of thanks to the author for his paper. Without professing to be an electrician, Mr. Dobson was one of those engineers who nevertheless had come conspicuously to the front in the way of utilizing electrical science to the utmost. At the last autumn meeting in London he had given the Institution a most interesting account of what he had succeeded in doing in the way of inverted-arc lighting in his own workshops (Proceedings 1893, page 396); and in the present exceedingly interesting paper he had now shown how he had carried out in his own shops, and carried out successfully, an electrical process involving so many difficulties that it had puzzled and apparently even baffled several of his predecessors. This electric welding process had such great advantages in cleanness, quickness, and certainty, that he could not help believing it would come into much more extended use than at present in cases where repetition work had to be carried out. It would be well worth while he thought for those interested in the process to work specially at its application to chain making. By its use he was not without hope that steel chains might be obtained quite as trustworthy as the present iron chains, and possibly 60 or 70 per cent. stronger, weight for weight. But at present this matter seemed hardly to have been seriously dealt with.

Mr. DOBSON wrote that since the meeting he had had an opportunity of examining at the Antwerp Exhibition the process of Lagrange and Hoho for heating metals by electric force, to which he had referred in page 355. It would appear to him that this process, however adaptable it may be in the future, has not yet assumed a practical form for ordinary workshop manipulation; up to the present in fact it simply replaces the ordinary smith's hearth by a heating apparatus, the heat of which is furnished by electricity. As he saw the operation performed, two small bars were pieced together; one was first heated in the chemical bath, and then hammered on the anvil to form a scarf for the weld, and then the other piece was similarly treated; then both pieces were heated together to a white heat, and taken to the anvil and welded together by hammer, after which they were swaged in the usual way.

It is a fact that, by covering with non-conducting material any portion of the metal plunged into the bath, the heat can be applied where desired. In the operation which the author saw, an india-rubber tube was slipped over a bar, and the bar became heated on both sides close up to the india-rubber, leaving the covered portion unaffected. Whether this would be practically useful, and to what extent, is of course a matter for experience; but it is easy to imagine circumstances under which this peculiarity would be highly useful.

The author had no means of testing the horse-power in any way; but it would seem to him that the amount of horse-power would not be so great as has been supposed. The extraordinary rapidity with which the bar became heated was also remarkable.

One essential difference between this method of heating and the heating on the Thomson-Houston principle lies in the fact that the exterior of the bar plunged into the alkaline bath becomes heated immediately, while the centre of the bar may remain cold until affected by the conducted heat from the exterior; this condition of course varies with the nature of the metal, and the size of the piece operated upon. It struck the author also, although on these points he could get no information, that in dealing with steel the extreme difference of heat between the exterior and interior would certainly

produce interior fractures on account of the difference of expansion. He thinks this must be so, at any rate for the finer classes of steel; and the difficulty there always is in treating this material, even when the greatest care is exercised, would be considerably increased thereby, and would seem likely to render impossible the employment of this rapid heating.

To sum up, the author's impression is that, although ingenious and possibly called upon to play an important part in engineering industry in the future, at the present time this process has not advanced beyond a highly interesting scientific experiment.

DESCRIPTION OF TWIN SCREW-PROPELLERS WITH ADJUSTABLE IMMERSION, FITTED ON CANAL BOATS.

BY MR. HENRY BARCROFT, OF NEWRY.

Canal-Boat Propulsion.—It is pretty generally known among those acquainted with canal traffic that until lately it has been impossible satisfactorily to navigate Canal Boats on the ordinary canals of the country by direct Steam Power; and boat-hauling, except under favourable circumstances, is still carried on by means of horses. A canal barge is usually made as full in every dimension as possible, the limit being the size of the canal locks to be passed through: so that there is no space at the sides or stern for paddle or stern wheels, nor is there a space forward of the stern post available for a screw. Even if space were reserved here, it would admit of only a small propeller, too small in area to be effective at slow speed, and liable to get entangled in weeds. Nor would there be what is termed a "run aft," to allow a flow of water to supply the place of the water driven astern by the thrust of the screw. If a boat were well proportioned for carrying a large and paying load, the action of a common propeller would be in proportion prejudiced; and, instead of the massive boat going forward, the power would be wasted in driving a small current of water astern at a more or less considerable velocity.

Conditions essential.—In endeavouring to solve this problem in navigation, the writer regarded certain conditions as essential to success, which may be thus enumerated. First, that any mechanical means employed should be applicable to almost every existing boat, if possible without any structural alteration. Second, that any propeller when applied should not interfere with the passage as at present through locks and under existing bridges. Third, that no

cargo or crew space should be sacrificed. Fourth, that the weight of the machinery should not seriously affect the carrying power of the boat. Fifth, that the action of the propeller should not be prejudicially affected by weeds. Sixth, that no wash should be originated, sufficient to affect injuriously the banks of a canal.

For the purpose of attaching any kind of propelling machinery, these considerations exclude every part of a boat otherwise available, except the space at each side of the rudder; and the question then arose how best to utilize this space by the employment of propellers of sufficient area to cause the boat to go forward satisfactorily. The effort of every propeller expends itself in two directions, driving the water astern and the boat forward; and the definition of excellence given by Rankine is to the effect that, other things being equal, the best propeller is that which drives the greatest volume of water astern at the slowest speed. (See "The Engineer," 2 Nov. 1866, page 339.)

After many experiments, extending over two or three years, upon a 60-ton lighter purchased for this special purpose, the arrangement was evolved which is the subject of this paper, and which is found by experience to comply with all the foregoing stipulations.

"*Newry.*"—The last boat fitted, the "Newry," is shown in Plate 85, and also in Figs. 3 to 5, Plates 87 to 89. Fig. 3 is a side elevation of the aft portion of the boat with the propellers, Fig. 4 a plan, and Fig. 5 an end elevation at the stern. Figs. 6 to 8, Plate 90, show details of the propellers. The boat is 62 feet long by $11\frac{1}{2}$ feet broad, with $5\frac{1}{2}$ feet draught fully laden, when, inclusive of machinery, she would have about 65 tons on board. Her machinery, weighing in all about three tons, consists of one locomotive boiler having 87 square feet of heating surface and weighing 23 cwts.; one horizontal engine with two cylinders, $4\frac{1}{2}$ inches diameter by 8 inches stroke, placed on the deck immediately forward of the stern post. On each side, coupled to the crank-shaft, are skew wheels W 12 inches diameter, driving wheels of the same diameter and of double the number of teeth on upright shafts S, which are set in upright frames F securely clamped to the foundation framing, as shown in Figs. 6 and 7; and the foundation framing is secured firmly

to the deck and deck beams of the barge. At the lower part of the upright frames are axles bolted or welded on at right angles, as shown in Fig. 8; and upon these axles revolve the twin screw-propellers, to which motion is conveyed by means of bevel wheels, one on the lower end of the upright shaft, and the other on the propeller boss. The interior of the boss is similar in design to what are called "patent axles" of road carriages, but suitably proportioned for the strains and work. The thrust is taken by a collar C, Fig. 8, on each face of which is a leather ring, the whole working constantly in oil, as is the case with all carriages. By this arrangement a saving is effected as compared with an ordinary screw working through a stern tube, which is necessarily subject to great friction. The diameter of the axle is $2\frac{1}{4}$ inches and of the collar $4\frac{1}{2}$ inches, giving an area of 12 square inches to take the thrust. The leather rings are each about 3-16ths inch thick. The skew wheels used in this instance for gearing the engine crank-shaft to the upright shafts are really worm gearing, as shown in Figs. 9 and 10, Plate 91; the worm on the horizontal driving shaft has 16 threads of coarse pitch, having an inclination of 27°, while the worm-wheel on the top of the upright driven shaft has 32 teeth inclined at the same angle to its axis or at an angle of 63° to its face; hence the upright shafts and the propellers are driven at half the speed of the engine.

Screw Propellers.—The twin propellers, right and left handed, are 4 ft. 10 ins. diameter, and have each three blades, and each blade has an area of 4 square feet; thus the total blade-area is 24 square feet. The blades made of thin steel are riveted to arms, which in turn are screwed into or against the boss, as shown in Fig. 8, Plate 90. The dimensions have been arrived at after numerous experiments, the great aim being to attain, subject to certain limitations, the utmost possible progress of the boat in proportion to the amount of coal consumed. The pitch of the blades is equal to 1,000 revolutions per mile; and at full speed the propellers make 100 revolutions per minute. It is not asserted that the diameter or area or pitch of the screws is absolutely the best; but from experiments with various diameters, areas, and pitches, the writer is

unable to suggest any decided improvement, so long as the power and piston-speed &c. remain constant. Every change in these last would naturally involve a reconsideration of the proportions throughout.

Crew.—The crew consists only of a man and a boy, who have had no difficulty in handling the boat and machinery under all the varying circumstances in which they have from time to time been placed.

"*Ulster.*"—The "Ulster," built a year ago and similar in many respects, has now accomplished 3,000 miles. Sometimes in Lough Neagh she has encountered considerable seas, Plate 92. On the Ulster Canal she has navigated up to Clones, 81 miles from Newry, through sections of 91 square feet, or only half as large again as her own immersed section; and in the Newry Canal she has passed through weeds so thick as to meet across the water; altogether the navigation from Newry to Clones is as difficult as any to be met with. These boats are very efficient as tugs. The "Ulster" towed a lighter laden with coal from Newry on the coast to Benburb on the Ulster Canal, a distance of 46 miles. The united cargoes of the tug and the lighter amounted to 107 tons. In this trip a length of 13½ miles in the Bann River and Lough Neagh was done in 4½ hours; the revolutions of the propellers were approximately 14,580 each, the revolutions due to the distance being 13,000; the coal consumed was 2½ cwts. The leathers in the nave of the propellers had not been examined up to the end of May, although the tug had run 2,350 miles; on examining them in June the author could see no wear on them, and the propellers are at work again without any change having been made. One cause which may tend to diminish their wear the writer is inclined to think may be that the pressure on the teeth of the lower mitre wheels transfers part of the thrust to the footstep of the upright shaft, thereby relieving the leather rings to that extent.

Immersion of Propellers.—The propellers, which have never been wholly submerged, are readily raised and lowered, so as to regulate the immersion and thus secure the utmost efficiency. If they are too

low, the engine is held by the increased resistance of the water, and the revolutions are restricted; while if they are too high, the engine runs away owing to diminished resistance, and a loss arises from excess of slip. The boatmen soon get to know the level that gives the best results, which for a full boat with $5\frac{1}{2}$ feet draught is about 3 ft. 3 ins. to 3 ft. 6 ins. from the surface of the water down to the bottom of the propeller. The two propellers are adjusted independently of each other. A portable crane P, shown in Plates 87 and 89, is dropped into a socket cast in the bed-plate at each side, and a long screw as shown is hooked to a ring on the propeller frame F; on slacking the clamping eye-bolts B, Figs. 6 and 7, the frame is suspended from the crane, and is then raised or lowered by the screw. Other methods have been used, but this plan has been selected as convenient and inexpensive, as well as being light and portable.

It is a peculiarity of these partially submerged propellers that they have little or no influence upon the steering of the vessel; that is to say, if one propeller were going ahead and the other astern, they would stop the way of the boat, and not tend to turn her round. For going ahead the propellers, being right and left handed, turn in all cases towards the stern post in the upper half of their revolution. In place of twin propellers, a single propeller has been used with good results, though working on one side of the stern instead of centrally. Two, three, and four blades have been tried; all are effective, but two cause an undesirable vibration; three are most efficient, while with four blades the vibration ceases but the efficiency is somewhat lessened, owing probably to what is called churning the water.

If desired the whole propelling apparatus can be made portable, and readily moved from one boat to another. The only alteration that is needed for an existing boat is an extension of the stern post, so as to set the rudder farther back; a space of from 15 to 21 inches is needed between the stern sheeting and the rudder when put square across: and most boats can pass the locks with this addition.

Performance.—In April last the Grand Canal Co., Dublin, fitted their No. 34 lighter with machinery similar to that above described.

The first voyage was from Dublin to the Shannon and back, Plate 92, having another boat No. 35 in tow. The distance there and back is 158 miles, with 78 locks. The second trip was over the same distance, and the time occupied about six days. In this trip the coal consumed in the double journey was altogether three tons at 14*s.* 6*d.* per ton, or at the rate of less than $1\frac{3}{4}$*d.* per boat per mile. On the Grand Canal it is usual to work night and day with relays of horses and men, and the time required out and back is five 24-hour days; the regular charge for hauling of one shilling per boat per Irish mile would be equivalent to nearly $9\frac{1}{2}$*d.* per English mile. So that, without working at night, the steam tug was only one day behind the horse boats in a week, notwithstanding that about fifteen hours were lost by the steamer in waiting for the locks to be filled after she had passed through and for the subsequent passage through of her consort.

Machinery.—The propeller bosses and arms have from the first been manufactured by Messrs. Grice and Harrison, axle-makers, of Birmingham. The blades and all the rest of the machinery for the "Newry" and for No. 34 lighter were constructed by Messrs. Robey and Co., of Lincoln, who have kindly supplied the accompanying drawings.

Driving by Petroleum Engine.—The new propellers seem admirably adapted for almost any method of driving. Fig. 11, Plate 91, shows an arrangement by which power is derived from a petroleum engine. Here the engine is represented on deck, 12 feet forward of the rudder; it rises only 2 ft. 8 ins. from the deck, thus enabling a light boat—that is, one without cargo—to pass under low bridges. If however the nature of the navigation should make it desirable to put the engine below, this can readily be done.

"*Hilda.*"—A very suitable arrangement has been adopted by the Portadown Carrying Co. for their steam lighter the "Hilda," Plate 86, of 80 tons burden, which navigates Lough Neagh, the largest lake in the United Kingdom, being 24 and 12 miles in

extreme length and breadth, Plate 92. Also the Lagan Canal to Belfast, where bridges are met with so low that the arch is but 2 ft. 4 ins. above the deck of a lighter when empty. No option remained but for the boiler, made by Messrs. Victor Coates and Son, to be put below. On deck, close to the upright shafts, are the engines, one for each propeller, which were supplied by Messrs. Vosper and Co., of Portsmouth.

Electricity.—A desirable combination would be to introduce electricity for conveying power from an oil engine, placed in any suitable part of the vessel, to the propellers. The engine could drive a generating dynamo, which in turn could set in motion a motor wound on the cross horizontal shaft H in Fig. 11, Plate 91. By means of resistance frames, various speeds could be obtained and reversing be accomplished, as on an electric railway.

Discussion.

The President said that since the paper was prepared the author had received from the managing owner of the Portadown Carrying Co. the following letter respecting the working of the machinery supplied for their steam lighter the "Hilda," which supplemented the brief mention already made of that vessel :—

Edenderry, Portadown.

Dear Mr. Barcroft, 18 July 1894.

I am sure by this time you will be anxious to know how the "Hilda" has done. I may tell you at once I am thoroughly satisfied with her. I have made several experimental trips with the view of finding out the best immersion for the propellers, and generally the speed I should like my man to work her at. One trip was to the

foot of the Coal Island Canal and back, a distance of thirty miles. On the return journey we towed the "Hibernia," a ninety-ton iron lighter, carrying about fifty tons of sand; also the "Emma," a seventy-ton barge, which was empty. I have made a number of trips to Whitecoat, exactly $1\frac{1}{8}$ mile from here; and I find the speed when empty, with the propellers running at 75 revolutions per minute and steam pressure of about 70 to 75 lbs., to be six miles per hour. The nominal full speed would be 100 revolutions for the propellers, with 100 lbs. boiler pressure; but I have never pushed her to this, and I think on the whole I shall keep to the speed I have mentioned, as the machinery will then be working under power, and there seems every probability of its wearing a long time. I cannot help feeling almost surprised at the result obtained, considering that the "Hilda" is as bluff in her build as any ordinary lighter, as I was anxious not to diminish her carrying capacity. Before putting her on the Belfast line I am about to send her for a load of sand, about ninety tons, which is a large cargo for a 60-foot boat. I should add we ran up to Scarva, eight miles from here, up the narrow weedy Newry Canal; the time in returning, including locking, was two hours and nineteen minutes. I must also add that the machinery causes no perceptible vibration, and that any of your friends will be welcome to a full inspection of the boat at any time. You will be amused to hear that when we started for Coal Island Canal none of us knew how to start the engines, the fitter having left suddenly. I have two men in charge, one brought up to the barge work, and the other a handy man from the weaving factory. Both are doing their work well, and now seem quite at home with the machinery.

Faithfully yours, HAMILTON ROBB.

Mr. J. HARTLEY WICKSTEED, Member of Council, noticed that on the "Hilda," Plate 86, there was an engine for each screw; which would render it practicable to drive each screw direct from its own engine through a bevel wheel and pinion. If the "Hilda" was fitted in that way, he should expect a greater efficiency than where the power had to be transmitted through skew gearing, as shown in Figs. 9 and 10, Plate 91, for the "Newry."

Capt. CECIL C. LONGRIDGE failed to see that adjustable immersion of the propellers would be of any practical use. The practice of most builders of launches and of other small boats was to put the screw as low as possible. The best immersion was always calculated for the greatest load intended to be carried. It appeared to him doubtful whether any practical builder would consider that the advantage gained from adjustable immersion was worth the greater complication of machinery. For $5\frac{1}{2}$ feet draught he observed that the best immersion was given as only 3 feet 3 inches to 3 feet 6 inches; this he supposed would very likely be the lowest position in which the screw could be put, and when the boat was lighter the screw would raise itself more out of the water. Driving by gearing he thought was objectionable where the screw propellers were running at high speeds of 200 or 300 revolutions per minute, as was mostly the practice. He saw no object in running propellers at few revolutions, for the injurious wash on the banks arose, he thought, not from the velocity of the screw, but from the lines of the boat and her speed; a propeller churned the water, but created little or no wash.

Mr. LESLIE S. ROBINSON asked why the propellers were kept only partially immersed. It was generally recognised that directly propellers began to suck air down into the column of water propelled astern, as partial immersion would render them liable to do, their efficiency dropped 25 per cent. or more. From the data given he was inclined to think that the propellers were too large for the work they had to do: especially from the statement that directly they were deeper immersed, though never wholly submerged as it would generally be considered they ought to be, the engine was pulled up. If they had ever been tried wholly submerged, though apparently they were never so employed in actual working, it would be interesting to know the results. He enquired also why the blades had been made so broad, and whether the pitch was uniform or varying. The area of the blades certainly seemed enormous; and 100 revolutions per minute seemed low for their full speed. For sea-going vessels the leather rings would of course be an impossibility, although in fresh water they seemed to work

well. The wash and waves he should have imagined would be likely to be greater with propellers working partly out of the water than when they were wholly under the water. Moreover he did not understand how these larger propellers partially immersed could be less likely to be clogged with weeds than a small propeller placed in the ordinary position, to which reference was made at the outset of the paper. As to the use of electricity, he feared that, from the number of transformations which would have to take place—from the oil engine to the dynamo, from the dynamo to the motor, and from the motor to the gearing—it was doubtful whether the plan would work out in a practical manner; the problem was one of great difficulty. The conditions under which the author was working were certainly exceptional, and no doubt exceptional means must be taken to solve them. Whether the best means had been chosen he was rather doubtful in the absence of adequate data. The power of the engine had not been stated, and therefore the loss could not be calculated. The slip apparently amounted to only about 10 per cent., which was not a bad result.

Mr. John A. F. Aspinall, Member of Council, asked how it was intended that the thrust should be taken up. There was an overhanging vertical frame at the stern, and apparently the whole frame could be made to descend into the water, thereby lengthening what was originally an overhanging lever; and there seemed to be no other provision for transmitting the thrust of the propellers to the boat. Was there any dead wood at the stern of the vessel for the vertical frame in which the propeller was suspended to abut against? With regard to the application of electricity for working canal boats, it appeared to him that there was here an opportunity of working boats by means of the trolly system, because along canals there would not be the objection to the overhead wires, which were thought to be ugly in towns.

Mr. Thomas Parker thought the proposal to work canal boats by electricity was not a desirable one in the present condition of

(Mr. Thomas Parker.)
the canals themselves. In conjunction with Mr. George R. Jebb he had been engaged upon an investigation into the driving of boats on canals by electricity; and the difficulties encountered were not connected with the overhead wires, but arose from finding that the boats could not be got through the locks with sufficient speed to give any hope of carrying on a traffic that would pay for the outlay. No doubt the driving of boats by electricity would be a thorough success, if the locks were arranged to admit a traffic sufficient to pay for the outlay.

Mr. James Platt, Member of Council, thought the method described in the paper did not give the best adaptation of steam power to boats on canals and rivers, but an ingenious application of steam power to existing barges, or barges built in the ordinary way; to old marine engineers it was rather alarming to look at some of the tackle shown. As to the partly immersed propellers, he remembered that some forty years ago the late David Napier, the pioneer of passenger steamboat traffic on the Clyde and on the Thames, had retired to a place near Worcester, on the banks of the Severn, and built a boat about 110 feet long and 17 feet beam, which had two screw wheels of 5½ to 6 feet diameter, placed so as to be about half above the water line, and driven direct by rotary engines on the shafts. The lines of the boat were fine, and she attained a tolerable speed in smooth water; but was utterly useless for manœuvring and backing, and for all the requirements of a steamboat. He himself had to take all the machinery out, and to lengthen the boat sufficiently for adding a stern wheel. The employment of the partly immersed propeller therefore was not new. Its application in the present case appeared to answer the purpose; and no doubt it might be modified, and perhaps made more ship-shape if applied to new barges built for the purpose. It was a desideratum in many cases to apply machinery to the present barges or to barges built in the ordinary way. The twin screw he considered was the best arrangement for barge propulsion; and some he had built twenty years ago were giving excellent results with a low consumption of fuel. The boats so

fitted propelled themselves at a good speed, and were also good tugboats.

Dr. Edward Hopkinson thought that, although the suggestion to employ a dynamo and motor in the way described in the paper might involve entrenching somewhat upon the cargo space of a barge, yet it might be useful for keeping the deck of the barge more free from machinery, and also for balancing the weight better. But the application of electrical working he was inclined to think would be more advantageously carried out by the adoption of overhead wires carried over the waterway, suspended by stretched cross wires attached to poles on the banks. Communication with the barge could be by means of a collecting bar extending across the full width of the barge. There should indeed be two collecting bars, one fore and the other aft, so that the conducting wire should always be lying upon one or other of them; as the wire hung freely in festoons, the fore bar would then come in contact with the next bight ahead before the aft bar had broken contact with the bight it was about to leave behind. This arrangement largely got rid of the difficulties attending the American plan of a trolly running along the suspended conducting wire. The contact of the conductor was much more easily accomplished, as it could slide freely along the whole length of the collecting bar across the barge. Such an arrangement he thought would be easily applied in connection with canal traffic, because the curves were usually of large radius; and for turning round a sharp corner, or for manœuvring at locks and wharves, the boat-hook was always available. The advantages of such a system of propulsion would be great. The motors being small and light, and no fuel having to be carried, the carrying capacity of the barge would not be entrenched upon to any appreciable extent. The motors would require less attention than a steam engine or oil engine. Again along the course of many canals there was water power available, which might be used for driving the generating dynamos. Where this was not the case and steam engines had to be employed, their efficiency would be high, because canal boats usually travelled night and day continuously, and therefore the load factor of the engines would be large.

Mr. Jeremiah Head, Past-President, wished to point out that the skew wheels through which the engine drove the propellers in the "Newry" were simply a form of worm wheels. It was often exceedingly tempting to use these appliances where it was wanted to diminish speed with a minimum amount of gearing, or to change the direction in a simple way; and they were quite unobjectionable when used in hand gearing or for similar purposes; but where used for conveying the whole power of an engine, they were in his opinion highly objectionable. This would be easily realized by referring to the drawing of the skew wheels in Fig. 9, Plate 91, in which the thickness of the engine wheel was seen to be about $3\frac{1}{2}$ inches, while the circumferential length of one of the teeth was about double as much, or 7 inches. In order for the engine wheel therefore to move the propeller wheel through the space of $3\frac{1}{2}$ inches, it must itself move through a space of not less than 7 inches, and must do so under the full pressure required to turn the vertical shaft from which the propeller was driven. At the bottom of the vertical shaft, where there was the bevel gearing of about the same diameter, it was evident that the pressure per square inch between the teeth would be about the same as between the teeth of the skew wheels; but the circumferential distance through which the teeth of the bevel wheels remained in gear could not be more than one inch, while in the skew wheels it amounted to 7 inches, under the same pressure per square inch during the continuance of their contact. This meant of course a great loss of power, and also more wear and tear. Such an expedient he therefore thought was mechanically wrong, and ought to be avoided.

Mr. Charles Cochrane, Past-President, hailed with satisfaction the appearance of the present paper. The late Mr. Henry J. Marten in the latter years of his life had been greatly interested, together with himself, in seeking a solution of the problem of canal-boat propulsion; and had stipulated that, in order to facilitate the traffic out of the Midland Counties to the various ports of outlet for England, a compact engine should be provided which could easily be transferred from boat to boat, so as to economise when the boats

were lying idle. This condition he himself thought was fulfilled by the petroleum engine, which he observed was referred to in the paper as being possibly applicable to canal boats; but Mr. Marten had never been quite satisfied that the proper plan had yet been hit upon. The present approach to the practical solution of the problem was therefore most welcome to himself, as he considered it would give the commercial world a great advantage, in the Midland Counties at any rate, enabling them to escape from present difficulties of heavy freights in reaching the sea-ports. The injury to the banks of the canals, which was suggested as liable to be caused by the wash, would be guarded against, when widening the canals in the future, by walling them in, so that no wash should interfere with the banks as it would do now where they were made of clay; and of course the widening of the canals would be necessary for the larger barges which would have to be built. It was a mistake he thought to suppose that the boats described in the paper were intended for high speed. They were purposely adapted to low speed; at least that seemed to him to be what the author had evidently intended. The high speed customary in yachts and launches (page 368) was not intended to apply to canal barges: what was here wanted was a slow motion to carry heavy weights; and he thought the author had gone a long way towards attaining this object.

Mr. BENJAMIN A. DOBSON, Member of Council, had always taken a great interest in canal boats, and remembered as a lad the canals in the north of Ireland that were mentioned in the paper. It seemed to him there could be no doubt that anything which tended to reduce the cost of carriage and haulage on canals must be of advantage to the country through which the canals ran. It had evidently been the author's endeavour to make the simplest arrangement that could be applied to existing boats; and in this aim he had pretty well succeeded.

Respecting the use of worm gearing, he was led to take exception altogether to the objection urged against it, because in his own experience he had found that, if worm gearing was kept properly oiled, it was as good a kind of gearing as could be got to do the

(Mr. Benjamin A. Dobson.)
work. There was no back-lash. The whole gear could be made much lighter for the same work; and it enabled speed to be transformed into power, which was the object for which it was employed in the present instance, where the engine ran twice as fast as the screw.

With regard to the large propellers, it seemed to him that the slow surface-speed at which they ran was calculated admirably for canal work. Their action was more like that of the blade of an oar in the water; and although they were not wholly submerged, there would not be the objection of their taking down the air into the water, as was the case with the ordinary small quick-running propeller, because their speed was so slow that the air had a chance of escaping from their downward action. Moreover the wash would not be so great; and it was the action of the wash on the sides of the canal which he thought was after all the most serious matter. There was quite enough of it at present, when the canal boat was hauled by a horse at a speed of less than three miles an hour; and if it was much increased, the expense of maintaining the canal would be too great. The suggestion of walling the canal he feared would hardly meet with the approval of the shareholders. In France however he had seen a method whereby the wash was entirely avoided in the case of canal boats propelled by a screw: a circumferential cylindrical shield was fixed just outside the circle of the propeller, which seemed to have the effect of driving the stream of water straight aft; instead of spreading immediately to the banks, it was directed in a backward course along the centre line of the stern, and it seemed to have lost its speed before it touched the bank. He did not know whether the same device had been tried or found necessary in this country; but it certainly seemed to act successfully when he saw it working on the canals in France.

Mr. Ralph H. Tweddell was reminded by the mention of the use in France of a shield over the propeller (page 374) that he had himself taken part about thirty years ago in a contrivance of that kind at Sunderland, not his own invention. The propeller was a helical screw, built up of blades like those of a fan, and revolved within a

cylindrical casing. The latter acted in the way described, and had the additional advantage that it could be turned round horizontally to either side, as well as in a direction right aft, so that the boat could thereby be steered right or left, no rudder being required. The trial trip had been a perfect success, and he had thought favourably of the plan at the time; but he had never heard of it afterwards.

Mr. Matthew Paul, Jun., having had a great deal to do with the propulsion of small boats, had been struck by the peculiarity ascribed in page 364 of the paper to these partially submerged propellers, that they had little or no influence upon the steering of the vessel; so that, if one propeller were going ahead and the other astern, they would stop the way of the boat, and not tend to turn her round. This seemed to him almost to involve the inefficiency of the propellers. If the propellers were efficient he considered they would certainly have an influence on the steering of the boat when used in that way. The idea that a propeller could prove efficient when working with the tips of the blades actually emerging from the water seemed to him to be in the face of all ordinary experience in propulsion. The slow speed of the boat could not make any difference, so far as he could see, in the principle of the action of a propeller. It was universally found that, even when the tips of the blades approached the surface of the water, the efficiency was largely reduced, and when they broke the surface the efficiency fell off 25 or 30 per cent. The conditions under which the boats described in the paper were working did not appear to him to be such as should alter that result.

Mr. T. Hurry Riches, Member of Council, said that, in boats required for the smooth waters of canal channels, it had always appeared to him that the great desideratum was to use as fine a pitch as possible for the propeller, because then the stream of water from the stern flowed more directly aft, and the side wash so objectionable for the banks was to a considerable extent prevented. The finer pitch of course meant that the propeller had to be driven at a higher speed of revolution; but he was quite satisfied from his own

(Mr. T. Hurry Riches.)

experience of propeller working that in order to avoid the wash a fine pitch was wanted.

Mr. GEORGE CAWLEY said the experience of canal managers and engineers showed that the conditions of boats navigating canals were quite different from those of vessels in open water, in regard particularly to the resistance encountered and also in other respects. In the course of a long discussion upon a paper read ten years ago before the Institution of Civil Engineers (Proceedings 1884, vol. lxxvi, page 160), it had transpired that even canal engineers themselves were not at all agreed as to the best conditions of working. In illustration of the influence of section of waterway on speed of boat, an instance had then been mentioned (page 188) of a light steamer having an immersed cross section of only $2\frac{1}{2}$ square feet, and intended to attain a speed of 10 miles an hour, which in a canal of 123 square feet cross section could not be made to exceed $5 \cdot 62$ miles an hour. In a tunnel having a cross section of 90 square feet the speed fell off to $4 \cdot 8$ miles; and here the boat was followed by a wave 2 feet high, which if it had overtaken the boat would probably have swamped her. Such an experiment seemed to him to be conclusive against the attainment of any considerable speed upon canals.

Mr. W. F. RICHMOND had noticed that even the present canal boats were liable to injury from the lock gates being improperly or carelessly closed. The rudder was sometimes damaged by the gates, when their closing was delayed until the barge after entering a lock from the lower level had returned sternwards with the leaving water; or when the gates were closed too soon on a barge entering from the upper level. The propellers of 4 ft. 10 ins. diameter described in the paper appeared from the drawing to project from 2 to $2\frac{1}{2}$ feet behind the boat, besides occupying the full width of the boat; and he would therefore recommend, whether the propellers were protected by the weed guards shown in the drawing or by a cylindrical casing (page 374), that the supporting stringers on each side should be made strong enough to serve as fenders against anything which might otherwise strike the forward side of the propeller blades.

Mr. Henry J. Rogers had recently been making some screw propellers with no blades at all, but with one complete turn of the thread and small pitch; they were for electric launches intended to work on the upper Thames above the locks. The propellers were driven at a high speed, and had been found to answer admirably. The boats were propelled at a rapid rate, and there was little or no wash.

Mr. Arthur W. Spence wished to know what was the effect of the arrangement described in the paper, as compared with the ordinary screw propeller; and what means, if any, were taken to prevent the wash from injuring the banks of the canal. On the Grand Canal in Dublin many years ago his father had first introduced steam propulsion; but owing to the wash from the propeller injuring the banks so much, particularly in places where the canal was very narrow, it had to be discontinued. This experience led Messrs. Guinness to introduce their present fleet of steam lighters on the river Liffey, instead of on the canal.

Mr. W. T. Olive asked whether on entering a larger or a smaller section of channel it was found necessary each time to re-adjust the immersion of the propellers, or whether it was the custom to do so.

Mr. Barcroft said the skew wheels (page 367) were used for convenience, and so far they had not been found to be attended with any loss of power that was material. In all probability there was some slight loss, but not sufficient he thought to be set against their advantages. The use of skew wheels was not by any means a necessity. Where there was a separate engine for driving each propeller, either propeller when required could be driven from the other, using only one engine for driving both propellers. If for any reason it was desired to stop the propeller immediately driven, a key could be taken out, and the driving shaft would run loose through the nearest wheel, and the furthest propeller could be driven without driving the nearest. In most cases a dead-wood sponson was used for taking the thrust of the propellers (page 369); but this was not a

(Mr. Barcroft.)

necessity, the vertical frames being themselves strong enough and fixed securely enough for the purpose.

With these partially immersed propellers it seemed to be thought (page 368) that efficiency was quite out of the question; but he considered that the facts were against that idea. The total mileage run by the boats up to the present time was about 6,000, and they had traversed about 300 miles of waterway in Ireland. The northern canals were much worse in section that the Grand Canal. The latter had originally been a fine waterway, but it had since become diminished in depth through time and through not being dredged. The northern canals had still their original depth, but were choked up with weeds.

Since the paper was prepared, the managing owner of the steamer "Newry" had given him the figures of her working for twelve weeks. She came out from the hands of the builder Mr. Crawford at Newry on 5th May, and from that date to 26th July she had travelled 520 miles, and had carried a total of 440 tons in eight cargoes, the average weight of each cargo being therefore 55 tons. The expenditure for coal came to $3\frac{1}{3}d.$ per mile over the whole distance. The crew consisted of a man and a boy. On the "Ulster" there were two men, captain and mate, of whom the latter happened to be a militiaman; and about a month ago, when the militia were called out for training, the boat was at a place called Gilford, on the Newry navigation, fifteen miles from Newry (Plate 92). The captain however did not want another mate, and himself alone brought the boat into Newry, through twelve locks and fifteen miles of navigation, without any assistance whatever. As to danger in passing through locks (page 376), he did not know of any accident having ever happened in that way; and the boats had gone through thousands of times.

In regard to the waste of time in locking, which had been referred to as so serious an obstacle (page 370), on the Grand Canal he had taken the time, and had found that on one occasion a steamer went through a lock at Tullamore in a minute and a half: so that he thought the delay would not be serious, if there were proper arrangements for opening and closing the gates.

The reason why large propellers were more effective than small ones (page 368) he had endeavoured to illustrate by a sketch, Fig. 12, Plate 91. The small circle in the middle represented a propeller of say $2\frac{1}{2}$ feet diameter wholly submerged. The two large circles represented the twin propellers of say 5 feet diameter. If these were immersed to only half their depth, they would have four times the grip on the water that the small propeller would have. The effect of their having so much more water to act upon was that the wash was done away with; practically there was no wash. He had seen these propellers working with no more than 4 per cent. difference between the distance actually run and the calculated distance due to the revolutions: which he thought was probably as good a result as could be met with. When the section of the waterway became narrower, the slip, if it might be so called, became greater in proportion to the narrowness of the channel. On the same voyage in which he had noted the slip of only 4 per cent. in one place, it had risen to 68 per cent. in another where the waterway was but slightly larger than the immersed section of the boat. In that instance indeed the boat section amounted he believed to about two-thirds of that of the waterway, and the speed fell to 6-7ths of a mile per hour, whereas in the open it was 3 miles per hour. In so narrow a channel he thought an ordinary propeller would not move the boat forwards at all; in all probability she would even go back, notwithstanding that the propeller continued to revolve in the direction for forward progress; he had seen such a thing happen.

The propellers were not altered in vertical adjustment for change in section of channel (page 377), but only for change in load line. Each propeller was adjusted separately by means of the small portable crane, which was shifted from one side of the boat to the other.

As an illustration of the advantage of larger blades, on one occasion in his experiments in open water he had substituted blades of a smaller area, with which the number of revolutions to give a certain speed was about 90 per minute. On then replacing the larger blades the revolutions were reduced from 90 to 56 per

(Mr. Barcroft.)

minute, without any change in the speed of the lighter. This he thought was sufficient to prove that it was necessary to increase the blade area, within certain limits which could be arrived at only by practice.

The President thought it was a little doubtful whether, in some of the criticisms that had been offered upon the paper, the whole of the conditions which the author had had to meet had been fully realised. The designing of a marine engine to drive twin screw-propellers was work of an ordinary kind. But it seemed to him to be very different from ordinary marine work to have to design engines and propellers which should carry forward a barge under such difficult conditions as were here met with. He questioned whether any marine engineer who had not actually worked in this particular line could quite appreciate what the practical difficulties really were. Whatever they might be, he understood they had now been successfully met; and he hoped that later on, when there had been more time for working, the author might give some fuller particulars as to cost, coal consumption, and efficiencies, than he had at present been able to furnish. Meanwhile he had great pleasure in moving a vote of thanks to him, in which the members he was sure would heartily join, for the interesting information already supplied on so important a subject.

DESCRIPTION OF THE MANCHESTER MAIN DRAINAGE WORKS.

By Mr. WM. THOMAS OLIVE, Resident Engineer.

1. *Historical.*—The question of floods claimed the serious attention of the Corporation of Manchester when in 1872 the river Medlock rose to a height of 25 feet above ordinary water line at Pinmill Bridge, and caused an enormous amount of damage. But it was not until 1874 that a committee was organised to consider the prevention of floods; and their report in November of that year recommended the raising of the bridges and the removal of weirs on the Medlock, the clearing out of the river bed, and alterations to the weir at Throstle Nest on the Irwell. A report on the flood question, and in connection therewith on the interception of the sewage of the city from the rivers, was obtained from the late J. F. Bateman and J. G. Lynde in 1877. The Salford Corporation were the first to take active steps, by appointing a Conservancy Board for the whole watershed of the Irwell; and to them must be ascribed the credit of first launching out into extensive works of main drainage. In 1878 several of the adjoining local authorities sought to join in the Manchester scheme of sewage interception and treatment, but could not arrange a basis of agreement; consequently the idea of a joint scheme was abandoned in October 1879. In 1885 the Rivers Committee reported on the various systems of sewage treatment in operation at that time; and after consulting Mr. J. Bailey Denton they recommended in 1887 the system carried out at Leeds, as an example for Manchester to follow. The necessity for action was considerably hastened by the contemplated construction of the Ship Canal. After a prolonged enquiry the sanction of the Local Government Board was obtained on 16th March 1889, with some limitations and alterations; and instructions to carry out the scheme were issued by

the Council on 3rd April 1889. Accordingly in the autumn of that year the first contracts were let, and operations were commenced in the beginning of 1890. Since that time the work has been continuously in progress, and has comprised twenty-seven contracts for main intercepting sewers, tanks, buildings and machinery, and filtering beds.

2. *Area and Population.*—Previously to 1885 the area of Manchester was 4,296 acres, and the population 341,414. In that year the area was increased to 5,929 acres ; and in 1890 six townships were added, comprising an area of 6,861 acres: so that the total area is now 12,790 acres, and the population about 515,600. A general plan of the area drained and of the works is shown in Fig. 1, Plate 93. The plan now being proceeded with is an intercepting scheme, whereby as far as practicable the new main sewers are carried along the valleys at such depths as to intercept the existing sewers and convey all the sewage to one main outfall, which forwards it to the sewage works at Davyhulme, five miles distant from the city. A gravitation system has been aimed at and attained, although in some places at the expense of very flat gradients. Nevertheless it is believed that the sewers will be perfectly self-cleansing. The calculations for the sizes of the sewers have been based upon a present daily water supply of 20 gallons per head, together with 5 gallons as a margin for increase and for subsoil water : in all 25 gallons per head for a prospective population of 625,000, together with a rainfall varying in different parts of the district from 3-16ths inch up to ½ inch in twenty-four hours.

Rainfall.—The consideration of the rainfall was much simplified by an agreement entered into with the Ship Canal, the substance of which is as follows. The storm overflow sewer discharging into the Ship Canal at Mode Wheel is so constructed that nothing can flow through it, until with the addition of rainfall the volume flowing down the main outfall sewer at its junction with the storm overflow sewer exceeds six times the normal flow of sewage from the whole area draining into the main outfall sewer. If at any time the flow down the storm sewer should injure the water in the Ship

Canal, the Corporation can be called upon to raise the level of the weir at the junction to such a height that nothing can flow into the canal until the volume flowing down the main outfall sewer exceeds eight and a half times the normal flow of sewage from the whole area. In London the provision made for rainfall is one quarter of an inch distributed over twenty-four hours.

Subsoil Water.—From gaugings taken the author has been able to ascertain that the subsoil water entering the Manchester sewers per acre of sewer surface is at the rate of only 17,300 gallons a day, or 1·92 cubic feet per minute.

3. *Main Intercepting Sewers.*—The main intercepting sewers vary in size from 2 feet wide by 3 feet high to 14 feet wide by 10½ feet high. All the sewers up to 5 feet diameter have been built in two rings of brickwork; from 5 feet to 10 feet diameter in three rings; and the main outfall, which is 14 feet wide by 10½ feet high, in four rings. In the smaller sewers blue bricks have been used for the inner ring, and common reds for the outer or back ring. Both hydraulic lime and cement mortar have been used, whichever was considered most suited to the nature of the ground.

By far the larger portion of the work has been done in tunnel. The strata have been for the most part sandstone rock, boulder clay, sand and ballast, and a little running sand. The greatest difficulties to contend with have been presented by the old sewers, which to a large extent follow the same lines as the new, sometimes running about the same level, side by side, or crossing over, under, or through. In two instances men have been drowned, owing to the bursting of these dangerous and often badly constructed old sewers; and many times have the workings been flooded thereby. To cope with the work successfully required a great deal of ingenuity, and much thought and additional expense. Special ironwork has had to be made; and storm-overflow chambers have been built over the old sewers, wherever tapped, so that only the right amount of sewage and storm water should enter the new sewers, and the rest should flow over a weir and down the disused portion of the old sewers to the rivers. Twice have old tunnels, from the rivers Irk and Medlock to

adjoining mills, been cut through at great expense and trouble and some danger. In one place a disused canal branch, the existence of which was not known, was tapped, and the workings were flooded, the men narrowly escaping with their lives. The several river crossings call for no special mention; but it is worthy of note that in crossing under three main lines of railway—namely the Cheshire lines to Liverpool, the Midland line to London, Figs. 2 to 5, Plate 94, and the South Junction lines—although the crown of the sewer, 14 feet wide by $10\frac{1}{2}$ feet high, was within 2 feet of the sleepers, no accident occurred, nor were any trains ever delayed. At Erskine Street, Stretford Road, there is a large junction chamber or bell-mouth, where the combined flow of a 7 feet and a 9 feet sewer discharges into the main outfall sewer of elliptical section, 14 feet by $10\frac{1}{2}$ feet. The length of this sewer to the storm overflow chamber is about 3,535 yards or just over two miles; and it varies in depth from 37 feet to 45 feet below the surface of the ground.

Storm Overflow Chamber.—The storm overflow chamber itself is large, measuring $51\frac{1}{2}$ feet long by 27 feet 2 inches wide, as shown in Figs. 6 to 8, Plate 95; it has a weir running the full length along the side of the sewer, at such a height as to satisfy the conditions of the agreement with the Ship Canal.

Bridgewater Canal Crossings.—In passing under the Bridgewater Canal, as shown in Figs. 9 to 17, Plates 96 to 99, the main outfall sewer had to be constructed in two cast-iron cylinders, each 8 feet 9 inches diameter, owing to lack of headroom and to the stipulation that a depth of 9 feet in place of $5\frac{1}{2}$ feet was to be provided. The work was done half at a time by means of cofferdams made of sand; and the canal had to be temporarily widened in order to provide for an uninterrupted traffic. From the storm overflow chamber to the tanks, a distance of 4,259 yards or 2·42 miles, the main outfall sewer is diminished in size to 10 feet diameter with a fall of 1 in 2,000. It averages 15 feet deep, and has been laid in open cutting and through fields. A second crossing under the Bridgewater Canal occurs here; but the main sewer by gradual dropping increased the interval between the invert and the water level, which latter is the same as at the first crossing,

so that the headroom sufficed for a single cast-iron tube 10 feet in diameter.

Sewer laid through Running Sand.—The ground passed through has on the whole been good; but in places much water has been encountered, and some running sand. In Stretford Road on the 7 feet sewer, where a length of about 300 yards of running sand was met with in the inverts, the method shown in Fig. 12, Plate 97, was adopted. Short timber piles P were driven along each side of the bottom of the trench, surmounted by longitudinal capsills C and transverse sleepers S; and board piles B, strengthened by longitudinal walings W, held back the running sand along the sides of the trench while the invert was turned on the sleepers and carried up to the centre line, above which the sand was overlain by boulder clay. The latter was supported by four longitudinal side bars and three crown bars R, held apart by stretchers. As the building of the crown progressed, the four side bars were taken out, while the three crown bars R with the head trees and roof boards were left in permanently, and the space above the crown of the sewer was filled in with brick packing.

4. *Outfall Works.*—The Corporation are under obligation to treat chemically and also to filter subsequently through land the effluent of the dry-weather flow of sewage from the population of the city; equal at 4 cubic feet per head to a quantity of 2,400,000 cubic feet per 24 hours upon a total population of 600,000; or 2,500 cubic feet per minute, assuming one half the total flow to pass in 8 hours. The buildings are designed in a conventional style of architecture, and somewhat resemble a modern farm building. They are faced with Ruabon red pressed-bricks: the reason for this is the great durability of these bricks; and as the buildings are in an exposed situation, it was thought desirable and cheaper in the end to have them faced with good impervious bricks which would keep the walls dry.

Boiler House.—The boiler house, Plate 100, partly sunk below the ground level, is 70 feet long by 33 feet wide, which allows ample space for three Lancashire boilers, 30 feet long and 7 feet diameter, of which two only are required at present. It is lofty, and has an open timber

roof with large exhaust-ventilator at the apex, and is well lighted at the side and one end; the windows are solid wood frames, and the upper portions above the transomes are filled in with sheet glass and made to open. The end is divided into three bays by two brick pilasters, and the three spaces are filled in with wood framing; the upper portion is glazed, and is fixed in the rebate of the brickwork by means of large coach-screws in wood blocks built into the walls. Thus at any time, should a boiler require to be replaced, the whole or a portion of the wood framing can be taken down, and the boiler got out without damaging any brickwork. The feed-water is heated by a Green economiser with 96 pipes.

Engine House.—In the engine house, which is 70 feet by 47 feet and lofty, are placed duplicate engines for working the lime mixers, &c., two air-compressors and engines, accumulator with two hydraulic duplex pumps for working the sludge presses, dynamo and engine for electric lighting, and electric accumulator cased in by means of wood framing. The upper portion and the open timber roof are glazed. The roof is in two spans, with queen-post principals supported in the centre upon cast-iron columns. It has four exhaust ventilators at the top; the windows are similar to those of the boiler house, and are made to open. Two large gateways are made at the end of this portion of the building, for bringing in or taking out any of the machinery.

Lime-Mixing House.—The lime-mixing house is 82 feet by 27 feet, with gallery along one side and end for lime-mixers. The gallery is carried upon cast-iron columns, and the floor is formed with cement concrete arches supported upon rolled iron joists. Fixed on this floor are combined sewage-liming and lime-grinding machines, with agitators and driving gear and one milk-of-lime agitator. On the ground floor are provided lime-pits, into which dip the lower ends of the elevators that convey the lime up to the machines on the gallery floor.

Lime Store.—The lime store, 82 feet by 27 feet, is divided into five lime bunkers, each 19½ feet by 12½ feet. There is a stone staircase at one end and a store-room at the other; and a barrow passage 6 feet wide is provided between the lime bunkers and the

lime-mixing house, with openings in the two walls for allowing the lime to be drawn by means of a scraper to the lime pits of the elevators. A gallery 17 feet wide extends the whole length of one side, formed with rolled iron joists and cement-concrete arches, on which a tramway runs. The gallery floor is reached at one end by an inclined gantry, 11 feet wide, supported upon cast-iron columns and rolled iron joists, and having a plank floor with tramway for bringing the lime to the bunkers in wagons. The wagons are tipped on the gallery floor, and there the lime is slaked and then thrown into the bunkers. The haulage of the wagons up the inclined gantry is done by a large swivel-pulley and shafting worked from the main shafting. The roofs of the mixing house and lime store are open timber roofs, having queen-post principals with lantern lights and side louvre ventilators.

Press House.—In the press house, 82 feet by 50 feet, are placed seven pits, 12 feet by $8\frac{1}{2}$ feet, at an average depth of 34 feet; in these are fixed five rams or sludge receptacles, into which the sludge runs, and from which by means of compressed air it is forced up into the eight filter-presses overhead. The walls are cambered to these pits, except the division walls, and are lined throughout with Staffordshire blue bricks; openings with circular arches are left in the division walls, so that through communication between the pits is established. An upper floor is constructed in this house with rolled-iron joists and cement-concrete arches, supported upon cast-iron columns; openings are left in the floor under each press, for allowing the sludge cake to fall into the tip wagons when a press is opened. Two large sliding gates are provided at each end of the house, giving access for wagons under the presses. Two iron staircases are provided, leading to the upper floor. The building is roofed in two spans, with queen-post principals supported upon cast-iron columns in the centre.

Offices are provided in a separate building, one for the manager and the other for the chemist, with a board room over. Stables for four horses and loose box, mess room, store room, and weighing-machine office are provided in a separate building, with hay-loft over.

2 N 2

Settling Tanks.—There are eleven tanks, Fig. 18, Plate 100, all open to the air, each 300 feet long and 100 feet wide, having an average depth of 6 feet, a total water-surface area of about $7\frac{1}{2}$ acres, and a holding capacity of $12\frac{1}{3}$ million gallons. The floors are of cement concrete, and all the walls of brickwork. The floors of the tanks are level transversely, and rise 1 in 150 from the inlet end to the overflow end. After the sewage leaves the 10-foot outfall sewer, it flows through a screen at S, inclined at an angle of about 60° with the horizontal, by which all the larger matters in suspension are caught, and afterwards removed with a rake. Immediately behind the screen, the chemicals—sulphate of alumina and milk of lime—are added, and thoroughly mixed with the sewage by means of an agitator at A. The mixture then passes on into the sewage channel through the sluice ways at C or D, and is admitted into any particular tank by means of small sluices provided for that purpose, three to each tank. In sudden and heavy storms, when the amount of water is too great to be properly coped with and the sewage is largely diluted, the sluices at E may be opened, and a portion of the water run straight to the Ship Canal. The tanks being filled, the top water runs over a crest or weir W, and falls into the effluent channel, whence it flows at present down a tumbling-bay at B to the effluent conduit 8 feet diameter, and so to the Ship Canal. When the filtering beds are completed, which are now in course of construction, the sluice at B will be closed and that at H opened, so that the effluent may pass along the carrier and on to the beds, to be further purified before flowing into the Ship Canal. The tanks are constructed upon the continuous-flow system, and each tank is used for about five days before being cleaned out. The water to the depth of $4\frac{1}{2}$ feet is then removed by means of floating arms or decanting valves, and is delivered into 15-inch cast-iron pipes, which are suspended along the soffit of a subway that runs underneath the full length of the sewage channel; thence the water passes on to the low-level filter-beds. The remaining water is led into the effluent well F, and is lifted into the sewage channel for re-treatment. The sludge in the tanks is passed through valves into a semi-circular sludge-carrier in the subway, having a fall of 1 in 110, and is transmitted to the sludge

well L, whence it is pumped up by means of two Tangye pumps into the sludge pits; and after still further water has been decanted from it here, it flows to the ram pits by gravitation.

Filtering Beds.—The land owned by the Corporation for filtration, apart from that occupied by the tanks and buildings, is about 325 acres, namely 112 acres at Davyhulme, and 213 acres at Flixton two miles distant, Plate 93. Only 30 acres are at present laid out, in two beds. A concrete carrier 16 feet wide by $3\frac{1}{2}$ feet deep and 2 feet thick runs along the top end of the beds, and discharges the sewage thereon through 15-inch sluices placed at intervals of 25 feet. A centre bank divides the two filter beds, and a continuous bank surrounds both. The top of the banks is about $3\frac{1}{2}$ feet above bed level, and the beds have a fall of 9 inches in their length, or a gradient of about 1 in 800. A puddle wall 24 inches thick and $5\frac{1}{2}$ feet deep runs through the centre of all the banks. The beds are drained by 18-inch mains, socketed pipes with puddle joints, laid about 200 feet apart and parallel to the centre bank; into these pipes 6-inch agricultural drain-tiles laid 30 feet apart are connected herring-bone fashion. The mains connect with the effluent conduit, which runs under the centre line of the concrete carrier; their outlets are provided with tidal flaps, and are laid at an average depth of 6 feet. The filtering properties of the subsoil have not yet been thoroughly tested, but it is believed they will prove satisfactory. The soil is of a sandy loamy kind, almost free from sand and gravel, and therefore perhaps of a little too fine and close a nature; but the land was the best and most conveniently situated that could be obtained.

5. *Extension of Works.*—In addition to the area of 123 acres acquired in 1888, powers have since been taken for the acquisition of a further quantity of land for filtration, in the townships of Carrington and Flixton, near the junction of the Manchester Ship Canal with the River Mersey. This area, shown in Fig. 19, Plate 101, contains about 213 acres. It has been selected with the view of obviating the necessity for pumping the effluent, which can be delivered by gravitation upon 180 acres; and this area, together with the portions at Davyhulme devoted to filtration, amounts in the

aggregate to about 240 acres, which is estimated to suffice for a total population of 600,000, or at the rate of 2,500 persons per acre.

As the projected areas at Carrington and Flixton are approximately three times the size of that at Davyhulme, it has been thought desirable to design the effluent conduit of sufficient capacity to deliver upon them a quantity equal to the entire dry-weather flow of sewage, so that the filter beds at Davyhulme may at any time be allowed a period of entire rest; and the water for filtration will be delivered on to the Carrington and Flixton areas over a weir at the end of the effluent channel which runs along the breast of the precipitation tanks. The weir is 16 feet in length, over which the total dry-weather flow of 2,500 cubic feet per minute represents a depth of $9\frac{3}{4}$ inches. Immediately on its overfall side is placed a converging chamber, the width of which at its upper end is equal to the length of the weir, and at its lower end is contracted to the width of the effluent conduit; the breast of the weir and floor of the chamber are in longitudinal section a parabola, with a fall of 3·66 feet in the length of the chamber.

As the effluent water to be conveyed from the precipitation tanks to the filtration areas will be practically free from suspended matters, a sectional form has been adopted for the conduit, such as is frequently employed for purposes of water supply, affording a greater hydraulic mean depth than would be possible with any other form, due regard being had to available gradient and depth of flow, both of which in this case are limited. The vertical diameter of the conduit will be 6 feet and the horizontal diameter 7 feet, the gradient being 1 in 3,000; and with these dimensions and gradient, according to Mr. Beardmore's formula $D = A \times 55 \sqrt{2 H f}$, the discharge D of 2,500 cubic feet per minute represents a flow of 3·10 feet in depth, equal to about half the total depth of the conduit: A being the sectional area of the stream in square feet, H the fall in feet per mile, and f the hydraulic mean depth. As the fall from the level of the weir to the invert of the conduit is 3·66 feet in the converging chamber, the total dry-weather flow of effluent can be conveyed through the conduit with a considerable margin for possible increase, without the tail water backing up to the level of the weir. A length

of 230 yards at the commencement of the effluent conduit will be constructed as an open channel, fitted with sluices rendering it available as a carrier for the Davyhulme filter-beds. The length of the conduit will be 3,500 yards or practically 2 miles. Its course has been laid out with a view to interfering as little as possible with building land, and in a fairly direct line so as to avoid any sharp curves which would increase friction and retard flow. There is no curve of a radius less than 770 yards. A length of 180 yards crossing the valley at Bent Lanes will be constructed on a substructure of brick arches, and covered by an embankment. Generally speaking the work will be constructed in tunnel in two $4\frac{1}{2}$-inch rings of brickwork, the inner being of blue brick, with purpose-made skewback springers at the outer angles of the invert; and will be laid on a foundation of cement concrete. The sewer of the Barton rural sanitary authority, crossing the conduit in Bent Lanes, will be conducted under it by means of a syphon; and others at Woodsend Road and Irlam Road by cast-iron tubes of special construction. The invert of the conduit at Flixton where it enters upon the land is 48·14 feet above ordnance datum, being practically at the level of the ground. At this point is placed a distributing chamber, Plate 101, from which the main carriers F and C radiate in two principal directions: F proceeds in a south-easterly course and skirts the upper side of the land on the Flixton bank of the Mersey; and C in a south-westerly direction across the river to the land on the Carrington bank. The larger proportion of the land on the Flixton bank lies below a contour line 47 feet above ordnance datum; and the portion to be laid out on the Carrington bank lies below the 46 feet contour above ordnance datum.

The two main carriers F and C, Plate 101, will be constructed in concrete of differing sectional forms. That on the Flixton side F has a depth of $3\frac{1}{2}$ feet to water level, so that the higher portions of the land, lying between the contours of 47 and 50 feet above ordnance datum, may be utilized by drawing from the upper stratum of the flow; while that on the Carrington side C is not more than 2 feet deep, in order to reduce as much as possible the depth of the tubes suspended from the bridge by which the carrier crosses the river

Mersey. The main carrier F on the Flixton side will be continued from the distributing chamber with a gradient of 1 in 2,000, as it is the intention to maintain the water in this channel at as high a level as possible, drawing from it by sluices for the subsidiary carriers, which diverge from it generally at right angles and are placed 300 feet apart with gradients of 1 in 1,000; in these the flow will be regulated by steps and sluices with transverse carriers of smaller section, arranged so as to accommodate as far as possible the natural ground surface. The carriers, both large and small, will be designed to permit of the water being distributed in a continuous flow along each side of the carrier in such lengths as required, from properly regulated openings placed immediately beneath the coping level, so that the water shall be delivered to the whole surface of the filtration areas with as great regularity and uniformity as possible. The main and subsidiary carriers on the Carrington side of the river will be laid out on similar lines.

The areas served by each subsidiary carrier will vary from 7½ to 10 acres, these being again subdivided by smaller carriers; and the general level of surface will vary according to the ground from 15 to 30 inches below the water-level. The areas will be underdrained by 6-inch and 4-inch agricultural drain-pipes, laid in diagonal lines 10 yards apart at an average depth of 6 feet, and delivering into subsidiary drains, laid under the roads and barrow paths, and varying from 9 to 18 inches diameter. These subsidiary drains will be collected by a main underground drain, graduated from 2 feet to 5 feet diameter, discharging into the Manchester Ship Canal at a point immediately below the confluence of the Mersey, Plate 101; the water level of the canal at that point is 26 feet above ordnance datum, or 22·14 feet below the invert of the conduit at the point where it enters on the land. The main underdrain from the Flixton area will be conducted under the river Mersey, by means of two circular cast-iron syphon pipes, 36 inches diameter, and will be connected with the main drain from the Carrington area, as it is not practicable to obtain a separate outlet into the river. Manholes and ventilators, placed 100 yards apart, will be provided on all main and subsidiary underdrains, with shafts for aeration placed midway between them,

or about 50 yards apart. The several areas will be subdivided by roads and barrow paths, laid out to coincide generally with the lines of the main and subsidiary underdrains, and affording convenient access to every part of the land, and communicating with the existing roads outside.

The bridge across the river, Plate 101, connecting the Carrington and Flixton areas, will be of the lattice-girder kind, having a span of about 60 feet and a width of 18 feet, its flooring being laid on wrought-iron plates; cross girders with wrought riveted tubes will be suspended therefrom, for conducting the main distributing carrier to the Carrington side of the river.

The portions of the land lying above the available level for irrigation will be utilized for the erection of homestead, cottages, stabling and outbuildings, &c. In order that the employment of this land for purposes of effluent filtration may not render it in any way unsightly or objectionable to the neighbourhood, the banks of the river and the boundaries of the estate will be suitably fenced and planted with fringes of trees and shrubs.

6. *Machinery.*—The two pumps by which the sludge is pumped up from the sludge well into the sludge pits are fixed in the well L, Plate 100, and are of the horizontal direct-acting kind known as the "special" steam-pump, constructed by Messrs. Tangyes and embodying the most recent improvements. The steam cylinders are 12 inches diameter and the sludge barrels 9 inches diameter with a stroke of 24 inches, both double-acting; each pump is capable of raising 290 tons of sewage sludge in eight hours to a height of 32 feet, or the two conjointly 580 tons. The valves are constructed on the hinge or clack principle, the clacks being of wrought-iron faced with leather, and working on a cast-iron seat; the clack spindles are so arranged that the withdrawal of either of the valve-chest covers enables the valve to be removed with ease. Through these valves any foreign matter, even of considerable size, can pass without damaging the pump. The suction and rising mains are so arranged in duplicate that the pumps can be worked for the effluent water, thus ensuring a ready way of cleansing them of sludge. The

pumps are reliable and easily understood; and the steam consumption is reasonable for the work done.

After the sludge has remained for some time in the sludge pits, the top water is led off by means of decanting valves into the effluent well F, from which it is again raised by pulsometer pumps into the carrier. From the sludge pits the sludge gravitates to a well just outside the press house, and is admitted in succession to the five rams or sludge receptacles; whence, after the charge of milk of lime has been admitted, it is forced by compressed air at a pressure of 100 lbs. per square inch into one or other of the eight presses on the upper floor. The rams or sludge receptacles are of cast-iron in two parts with faced joints, bolted together with strong bolts and nuts, each receptacle having a 6-inch inlet-valve for the sludge and a 3-inch outlet-valve, with long spindle, brackets, and hand-wheels for working from the press floor-level. The tipping wagons, made to swivel so that they may tip either at the side or at the end, are passed underneath each press for the removal of the cake when liberated; and the expressed liquid is allowed to flow back into the main sewage carrier to be treated again.

Sludge Presses.—Each of the eight presses, Plates 102 and 103, is composed of a series of vertical plates 41 inches square, resting by side lugs on two horizontal tie-rods, on which they are free to slide, and from which they can be lifted when necessary by means of a small overhead traveller. At each end of the press the rods are supported on a strong fixed frame. At one end is an inner sliding frame, which is opened or closed by hydraulic pressure. When the press is closed therefore it contains a series of 45 vertical chambers with filter cloths on each side, giving to each chamber a filtering area equal to double the size of the plates, which are 44 in number to each press. The sludge is made to pass through the centre of the fixed end into these chambers, where the separation of the solid from the liquid takes place. The liquid filtering through the cloths runs down grooves in the plates and out through openings at the lower edges of the plates; the pressure is kept on until the water ceases to run, showing that the press is then full of cake. Provision has been made for six additional

presses if required. In sinking the ram pits a great deal of water was encountered in the red rock; this is now raised by a small ejector and utilized in the working.

Boiler and Engine.—The machinery in connection with the works is driven by steam from two Lancashire boilers made by Beeley, of mild steel plates; each boiler is 30 feet long and 7 feet diameter, having two flues 2 feet 9 inches diameter with solid-welded longitudinal seams, and transverse seams made with anti-collapsible flange joints having solid caulking rings between each flange. The main driving engine is horizontal high-pressure, with cylinder 10 inches diameter and 20 inches stroke; this drives the lime mixers, elevators, etc.

Air-Compressors.—Two air-compressors are provided, having steam cylinder 14 inches diameter and air cylinder 12 inches, with a stroke of 20 inches. Each engine and compressor is fixed on the top of a strong cast-iron air-receiver. The crank-shaft is furnished with a heavy fly-wheel at each end; the engine is also fitted with a high-speed governor, and equilibrium valve. The air cylinder is fixed behind the steam cylinder, and driven by the prolonged end of the piston-rod, with a coupling for connecting direct to that of the air-compressor. The valves and seats are of phosphor-bronze, and so arranged as to secure a full charge of air in each end of the cylinder, which is water-jacketed. The air-receivers are made in two halves, with flange joint turned and faced and secured by strong bolts and nuts.

Accumulator.—The accumulator stands in one corner of the engine house. It has a 7-inch ram, steel cylinder, guides and attachments, and automatic gear for controlling the throttle-valves, and is actuated by two hydraulic duplicate pumps of 9 inches diameter and 10 inches stroke.

Liming.—There are six combined liming and lime-grinding machines, and one milk-of-lime agitator consisting of a cast-iron trough, in which revolves a central shaft having cast-iron stirrers, gun-metal bearings, and fast and loose driving pulleys. Six elevators of the ordinary kind supply lime to these machines, by lifting it from the pits in the floor of the lime house. The agitator

at A in the inlet sewage-channel, Plate 100, is worked by a vertical engine with cylinder 6 inches diameter and $6\frac{1}{2}$ inches stroke, fixed on rolled joists in the effluent well F, driving the horizontal shaft of the agitator through bevel wheels. The lime is at present being admitted into the inlet channel immediately in front of the agitator, whilst the aluminoferric is supplied lower down the same channel. Provision has been made for an additional agitator should it be found necessary.

Communication has been obtained with the Ship Canal by means of a road and tramway, so that supplies of coal and chemicals may be delivered at the Corporation Wharf on the banks of the canal. Provision has also been made for hauling up trucks of lime to the high-level floor by a rope tramway.

7. *Electric Lighting.*—The installation includes a vertical engine with 13-inch cylinder and 16 inches stroke to run at 130 revolutions per minute with a pressure of 80 lbs. per square inch, the steam being supplied from the general service boilers. Also a set of 56 storage batteries capable of running with lamps of 16 candle-power a maximum of 420 lamp-hours. The dynamo is driven at a speed of 700 revolutions by a 10-inch flexible centre belt direct from the engine fly-wheel, which is $5\frac{1}{2}$ feet diameter and $11\frac{1}{2}$ inches wide on the face; it is of the inverted-magnet type, compound-wound, and has a capacity for working a 220-ampère load at 100 volts when on the lamp circuits. When charging accumulators a plug switch is inserted in the series portion of the compound winding, which cuts that part out of action. For charging the accumulators in series the speed of the dynamo would require to be nearly 1,000 revolutions per minute, with a corresponding increase in speed of engine. As this however would materially increase the wear and tear, the batteries by means of suitable switches are arranged in two sets of 28 each when charging. By this means the speed is reduced to about 600 revolutions per minute, thereby effecting also a saving of steam. Although storage batteries usefully yield only about 70 per cent. of the energy given to them by the dynamo, they are extremely economical and handy. If a small number of lamps only

are required, it would be wasteful to run the engine; besides which, time would be occupied in oiling and heating up, and there would be loss by condensation. From the accumulators the lamps can be started or stopped instantly without any further attention. As the insulated cables spread for hundreds of yards in every direction about the premises, the stored energy could be applied on an emergency to portable machines for pumping, drilling, hauling, etc. The number of lamps at present in use is 134, as follows:—14 arcs of 1,200 candle-power for outside use; 12 arcs of 500 candle-power for inside use; 88 incandescent lamps of 16 candle-power for inside use; 8 incandescent lamps of 50 candle-power on the approach road; and 12 incandescent lamps of 32 candle-power in the subway. These are divided on the switchboard into six main circuits, but there are also local switches for every one or two lamps, except on the approach road where all the lamps are controlled by one switch. An illustration occurs here of the economy of electric lighting as compared with gas. To light and extinguish gas would occupy a man at least an hour every day; whilst the engine-man can turn the electric lamps on and off in an instant without leaving his post. The electric lamps also require less cleaning, as there is no smoke or soot, and the insides of lanterns are sealed from atmospheric dust.

Discussion.

Mr. CHARLES HOPKINSON believed the attention of the Corporation of Manchester had been called to the subject of floods as early as 1860 or 1861; and by 1872 a large amount of money had been spent in making river walls along the course of the Medlock. The most serious river flood that had occurred in Manchester was the flood of 1866 on the Irwell; and he well remembered it was that flood more than any other, more even than that of 1872, which had stimulated action with regard to the rivers.

(Mr. Charles Hopkinson.)

After the sludge cake had been formed in the presses, he enquired how it was dealt with; and whether it was of such a nature as to induce farmers to take it, or whether it was disposed of by being burnt or carried out to sea.

With an unlimited quantity available of condensing water, however dirty, he asked why the engines had not been made condensing; and further why the electric accumulators were not yielding an efficiency more than 70 per cent., when there were various makers of storage batteries who would undertake to give a higher efficiency under reasonable conditions of working.

Mr. W. SANTO CRIMP said it should not be taken for granted that the conditions under which in London provision had been made for rainfall (page 383) were applicable there today. If the London drainage had to be done over again with the information now available, he was sure it would not be carried out in the same way. It was not sufficient to deal with the rainfall as though it were distributed over twenty-four hours; the rain fell at a much more rapid rate. During twenty-four hours it was said to average 0·01 inch per hour; but the average during the time the rain lasted was much more like 0·06 inch per hour.

Having regard to the depth of from 37 to 45 feet at which the main outfall sewer was laid below the surface of the ground (page 384), he asked why a circular section had not been adopted. It would not only be better in respect of carrying capacity, but it would also be stronger.

Having had twelve years' experience of sewage farming and sewage disposal, he thought the population of 2,500 per acre (page 390) was exceedingly high, having regard to the nature of the soil (page 389): though he had not seen the land that was used for filtration in the present instance. On so small a filtering area in proportion to the population he was rather surprised to learn that Manchester was successfully dealing with the sewage, even after it had been chemically treated; no doubt there was a good deal more yet to be known with regard to the filtration of sewage. Having been applied to by the Corporation of the adjoining borough,

he expected filtration on a large experimental scale would be in operation for Salford long before Manchester would have to consider the subject further. As to sludge disposal no doubt a good deal of valuable experience would be gained; and in due time the Corporation would be themselves the best judges of that matter.

Mr. Hugh S. Dunn asked if any experiments had been made to test the manurial value of the sludge cake. It would be of immense importance to the country if a process could be discovered whereby the fertilizing value of the sewage could be retained in the sludge in a soluble condition; this would make all the difference between a paying and a non-paying concern in many localities.

Mr. James B. Alliott, as the maker of the sludge presses erected at Davyhulme, said that they comprised some arrangements which were novel: not perhaps all of them novel in design, for several of them had actually been designed many years ago; but the novelty lay in carrying them out on any considerable scale. One point was the mode of closing the presses and keeping them closed by hydraulic power. In ordinary filter presses as generally used, the closing of the press, in order to resist the internal pressure on the sludge forced into it, had usually been effected by means of nuts tightened up by hand; and inasmuch as the pressure to be resisted was great, considerable manual power had been required for closing the press and making it tight. All this work was being done at Davyhulme by hydraulic cylinders, which not only closed the press but kept it closed during the pressing of the sludge. With the sludge actually found at Davyhulme, each of the presses in regular work was capable of turning out about one ton of cake per hour. The quantity of lime used would no doubt vary at different seasons of the year and according to the districts from which the sewage was coming, because the area from which the sludge had been coming to these works had been to some extent a changing area; but the actual quantity of lime used per million gallons of flow appeared thus far to have been about 12 cwts., which he thought would be found to

(Mr. James B. Alliott.)

compare favourably with the use of lime in many other places where sludge was being treated. The arrangements for keeping the hydraulic pressure upon the presses were made also to control the supply of the sludge to them: so that if, by the bursting of a leather of the accumulator or from any other cause, the accumulator should come down quickly and liberate the end of the press before notice had been given in the press-house and before the supply of sludge had been cut off, the supply would be cut off automatically by the falling of the accumulator itself. If that were not the case, when the pressure in the hydraulic main fell, every press would be opened out by the pressure of the compressed air, and streams of sludge would be blown out in every direction.

Mr. GILBERT LEWIS hoped an illustration would be added of the presses described in the paper, which were of much interest as a mechanical means of dealing with sewage sludge.

Mr. OLIVE said he had purposely omitted mentioning the flood of 1866, the most severe flood on the Irwell (page 397), because it was simply of local interest.

As to the disposal of the sludge cake, up to the present time the farmers in the neighbourhood had been only too glad to come and take it away almost as quickly as it was made. There was an old river course, now laid dry by the Ship Canal, in which the surplus stuff was deposited and covered over.

Non-condensing engines had been adopted mainly from their occupying less space and having fewer parts, compactness and simplicity being considered of more importance than economy of fuel. Moreover with condensing engines the cleaning out of the condensers and trouble with the air-pumps would have counterbalanced the economy in fuel.

As to efficiency of the electric accumulators, the moderate percentage given in the paper expressed what might reasonably be looked for in practice; and under general conditions fully this efficiency would be obtained. Much higher figures of efficiency were quoted by makers.

Regarding the rainfall (page 398), he believed the rainfall admitted into the sewers in London and carried down to the works had to reach an average rate of about a quarter of an inch in twenty-four hours before the storm-water overflows came into operation.

In the oval section of the main outfall sewer (page 398), the object had been to get as much carrying capacity as possible within the limited headway available under the three railways which had to be crossed (page 384).

The sewage from a population of 2,500 he agreed was a great amount to put upon an acre; but the conditions round Manchester were such that it was impossible to get sufficient additional land for reducing the quantity of sewage over the filtration area. Considering the nature of the stream into which the effluent had to flow, namely the Ship Canal, he thought a sufficient degree of purity would be attained to satisfy thoroughly the conservators of the canal. As to the agricultural value of the sludge cake, no experiments had as yet been made; some of it was at present being tried with barley and oats, and so far the results had been good. But the sewage varied greatly in its quality; sometimes it contained a quantity of flocculent organic light matter which was exceedingly difficult to deal with in the presses; it was apt to prevent the cake from solidifying in the press. As the drawings of the presses were in the possession of the makers, he had unfortunately not been able to illustrate this portion of the work.*

The President was sure the members would join in giving Mr. Olive a vote of thanks for his paper, which, although it had been discussed so briefly, would itself remain in the Proceedings of the Institution as a permanent record of these highly important works. Those members who were going to visit the works tomorrow would be particularly glad to have been thus prepared beforehand for what they would there see under the guidance of the author.

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* In response to the request made at the meeting, the two photographs shown in Plates 102 and 103 have been kindly furnished by Mr. Alliott.

EXCURSIONS.*

On TUESDAY AFTERNOON, 31st July, after luncheon in the refectory of the Owens College, two alternative visits were made. One was to the Corporation Electric Light Station (page 297), under the guidance of Alderman Lloyd Higginbottom and Mr. C. H. Wordingham, Resident Engineer; and afterwards to the Corporation Gas Works in Bradford Road (page 410), under the guidance of Alderman Lloyd Higginbottom and Mr. William Rodger, Manager.

The other alternative visit was to Messrs. Thomas Hoyle and Sons' Calico Printing Works, Messrs. S. and J. Watts' Warehouse (page 411), and the Printing Works of the "Manchester Guardian and Evening News."

The following Works in Manchester, Salford, and the neighbourhood were opened to the visit of the Members, as also on Wednesday and Thursday afternoons. Descriptions of most of these are given in pages 413–439.

Sir Elkanah Armitage and Sons, Cotton Spinners, Pendleton New Mills.
Messrs. Richard Haworth and Co., Cotton Spinners, Ordsal Mills, Salford.
Messrs. J. and N. Philips and Co., Warehousemen, 35 Church Street.
Messrs. Beyer, Peacock and Co., Locomotive Works, Gorton Foundry, Gorton.
Manchester Sheffield and Lincolnshire Railway Works, Gorton.
Messrs. Chadwick and Taylor, Ordsal Hall Paper Works, Salford.
Messrs. Nasmyth, Wilson and Co., Bridgewater Foundry, Patricroft.
Messrs. William Delany and Co., Packing Warehouse, Portland Street.
Manchester Crematorium, Chorlton-cum-Hardy.
Co-operative Wholesale Society, Balloon Street.
Chief Fire Brigade Station, Jackson's Row.
Messrs. Galloways, Knott Mill Iron Works, Chester Road, Hulme.
Messrs. Rylands and Sons, Merchants and Warehousemen, Market Street.
Manchester Royal Exchange, Market Street.
Messrs. Joseph Adamson and Co., Boiler Works, Hyde.
Messrs. Ashton Brothers and Co., Cotton Spinning Mills, Hyde.

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* The notices here given of the various Works &c. visited in connection with the Meeting were kindly supplied for the information of the Members by the respective proprietors or authorities.

Messrs. F. W. Ashton and Co., Calico Printing Works, Newton Bank, Hyde.
Messrs. Tinker, Shenton and Co., Hyde Boiler Works, Hyde.
"Manchester Courier," 22 Cannon Street.
Messrs. Hulse and Co., Ordsal Works, Regent Bridge, Salford.
Messrs. Kendall and Gent, Victoria Tool Works, Salford.
Messrs. William Muir and Co., Britannia Tool Works, Strangeways.
Messrs. Smith and Coventry, Tool Makers, Gresley Iron Works, Salford.
Engineering Laboratory, The Owens College.
Manchester Electric Light Station, Dickinson Street.
Manchester Corporation Gas Works, Bradford Road.
Manchester Ship Canal, Docks, Locks, Swing Bridge, and Swing Aqueduct.
Manchester Hydraulic Power Supply Station, Gloucester Street.
Manchester Main Drainage Works, Davyhulme.
Salford Corporation Gas Works, Liverpool Street, Salford.
Salford Corporation Sewage Works, Weaste.
Messrs. Yates and Thom, Canal Foundry, Blackburn.
Peel Park Museum, Salford.
Zoological Gardens, Belle Vue.
Blackpool Tower.
Manchester Corporation Water Works, Thirlmere.

In the evening the Members were invited by the Right Honourable the Lord Mayor, Sir Anthony Marshall, to a Conversazione in the Town Hall.

On Wednesday Afternoon, 1st August, after luncheon in the refectory of the Owens College, an alternative visit was made on the Manchester Ship Canal from Pomona Docks, in the saloon steamer "Eagle," to view Trafford Road Swing Bridge, Mode Wheel Locks, Barton Swing Aqueduct, and Salford Docks, under the guidance of Sir E. Leader Williams, Engineer, and Mr. Marshall Stevens, General Manager.

Another visit was made to the Corporation Hydraulic Power Supply Station, Gloucester Street (page 407), under the guidance of Mr. Frederic M. Evanson, Engineer and Manager; to the Manchester Shipping Offices and Packing Co.'s Warehouse, Lloyd's House, Lloyd Street (page 412), under the guidance of Mr. E. Durden, Manager;

and to the Chief Fire Brigade Station, Jackson's Row (page 413), where drill was performed, and a muster of the brigade summoned in Albert Square, under the direction of Mr. J. Lacey Savage, Superintendent.

In the evening the Institution Dinner was held in the Grand Hotel, and was largely attended by the Members and their friends. The President occupied the chair; and the following Guests accepted the invitations sent to them, though those marked with an asterisk* were unavoidably prevented at the last from being present.

Executive Committee.—The Right Honourable the Lord Mayor of Manchester, Sir Anthony Marshall, *Chairman*; the Right Worshipful the Mayor of Salford, Sir William H. Bailey, *Vice-Chairman*; and Mr. Charles Hopkinson, *Honorary Secretary.* Alderman Sir Bosdin T. Leech; Alderman Lloyd Higginbottom; Councillor S. B. Worthington; Mr. William Mather, M.P.; Mr. Joseph Adamson; Mr. Thomas Ashbury; Mr. John A. F. Aspinall; Mr. James F. L. Crosland; Mr. Thomas Daniels; Mr. Benjamin A. Dobson*; Mr. John Dodd; Mr. Wallis R. Goulty*; Mr. John H. Hargreaves*; Dr. Edward Hopkinson; Mr. Joseph W. Hulse; Mr. Samuel R. Platt; Mr. John Ramsbottom; Mr. Henry Simon*; Sir E. Leader Williams.

Authors of Papers.—Mr. Henry Barcroft; Mr. Samuel Dixon; Mr. Charles J. Hewitt; Mr. Wm. Thomas Olive.

Mr. George J. Armytage*, Chairman, Lancashire and Yorkshire Railway; Mr. John K. Bythell, Chairman, Manchester Ship Canal; Mr. H. Osborne Harley, Postmaster; Mr. Thomas P. Hewitt, Managing Director, Lancashire Watch Co.; Mr. Henry W. Holder, Registrar, The Owens College; Alderman John Hopkinson, Governor, The Owens College; Mr. William Hunt, Engineer, Lancashire and Yorkshire Railway; Professor Daniel J. Leech, M.D., The Owens College; Mr. G. E. Mawby*, District Superintendent, London and North Western Railway; Mr. S. Wilmott Newington; Mr. Thomas N. Robinson*; Mr. J. H. Stafford, General Manager, Lancashire and Yorkshire Railway; Alderman Joseph Thompson*, Chairman of Council, The Owens College; Mr. Henry Webb; and Mr. William B. Worthington.

The President was supported by the following Officers of the Institution :—*Past-Presidents*, Mr. Charles Cochrane, Mr. Jeremiah Head, and Mr. John Ramsbottom; *Vice-President*, Mr. E. Windsor Richards; *Members of Council*, Mr. John A. F. Aspinall, Mr. Arthur Keen, Mr. William H. Maw, Mr. James Platt, and Mr. T. Hurry Riches.

After the usual loyal toasts, the President proposed "The Corporations of Manchester and Salford," which was acknowledged by the Right Honourable the Lord Mayor of Manchester, Sir Anthony Marshall, and the Right Worshipful the Mayor of Salford, Sir William H. Bailey. The toast of "The Engineering Industries of the District," proposed by Mr. E. Windsor Richards, Vice-President, was acknowledged by Mr. Samuel R. Platt. Mr. John Ramsbottom, Past-President, proposed the toast of "The Owens College," which was acknowledged by Professor Daniel J. Leech, M.D. The toast of "The Executive Committee," proposed by Mr. T. Hurry Riches, Member of Council, was acknowledged by Mr. Charles Hopkinson, Honorary Secretary. Alderman John Hopkinson proposed the final toast of "The President," by whom it was acknowledged.

On Thursday, 2nd August, three alternative Excursions were made.

By special train to Royton to visit the Lion Cotton Spinning Mill (page 440), under the guidance of the Directors, the Manager Mr. John A. Kershaw, and the officials. Thence by special train to Mumps Station, Oldham, where the Corporation Electric Light Station (page 440) was visited under the guidance of Mr. S. Wilmott Newington, Resident Engineer. After luncheon in the new dining-room at Hartford New Works, by the kind invitation of Messrs. Platt Brothers and Co., their Machine-making Works were visited under the guidance of the Directors and staff (page 442).

By special train another excursion was made to Bury, where, by conveyances on the invitation of Mr. Henry Webb and the local Members, the Peel Cotton Spinning Mills (page 445) were visited

under his guidance, and also the Felt Hat Manufactories of Messrs. Adam Ashworth & Sons and Messrs. Lucas & Co. (page 447). The party proceeded to Rochdale by special train, to see, under the guidance of Mr. Thomas N. Robinson, Director, the Wood-Working and Roller Flour-Milling Machinery Works (page 448) of Messrs. Thomas Robinson and Son, by whose invitation the Members were entertained at luncheon in the works.

Another excursion was made to the Manchester Main Drainage Works (page 381) at Davyhulme, near Urmston, under the guidance of Mr. Wm. Thomas Olive, Resident Engineer.

In the evening a gala performance was given at the Theatre Royal, Manchester, on the invitation of the local Members.

On Friday, 3rd August, three alternative Excursions were made.

By special train to Bolton, where two parties were formed. One visited the Fine-Spinning Cotton Mill of the North End Spinning Co. (page 450), under the guidance of Mr. Herbert Mather, Managing Director, and Mr. Hilary S. Forrest; and also, under the guidance of Mr. Benjamin A. Dobson, Member of Council, the Kay Street Machine Works of Messrs. Dobson and Barlow (page 451), on whose invitation the Members were entertained at luncheon in the works. The other party visited the Soho Iron Works of Messrs. Hick, Hargreaves and Co. (page 454), under the guidance of Mr. J. H. Hargreaves; and the Globe Iron Works of Messrs. John Musgrave and Sons (page 455), under the guidance of Mr. Walter M. Musgrave; and on the invitation of Mr. J. H. Hargreaves they were entertained at luncheon at the Conservative Club. In the afternoon both parties proceeded by special train to visit the Locomotive Works of the Lancashire and Yorkshire Railway at Horwich (page 456), under the guidance of Mr. John A. F. Aspinall, Member of Council, Chief Mechanical Engineer.

Another excursion was made by special train to Crewe, to visit the Steel and Locomotive Works of the London and North Western

Railway (page 458), under the guidance of Mr. F. W. Webb, Chief Mechanical Engineer. On the invitation of the Directors the Members were entertained at luncheon.

Another excursion was made to Prescot, to visit the works of the Lancashire Watch Co. (page 461), under the guidance of Mr. Thomas P. Hewitt, Managing Director, and Mr. Charles J. Hewitt, Works Manager. On the invitation of the Directors, the Members were entertained at luncheon at the King's Arms Hotel.

MANCHESTER CORPORATION HYDRAULIC POWER SUPPLY, PUMPING STATION.

The buildings forming this station are in two blocks, divided by a roadway giving access to the yard and to the Rochdale Canal. The main building consists of an engine house, boiler house, accumulator tower, and coal store. The office block has a show room for hydraulic appliances on the ground floor, with offices above approached by a staircase with a hydraulic balance-lift working in the well-hole; behind the office is a residence for the foreman, with workshop and stores.

The engines are at present four in number; but two additional engine foundations are prepared, and it is possible that within a year the station will be completely furnished with pumping plant. The type adopted is the inverted triple-expansion surface-condensing pumping-engine, each engine upon trial indicating rather over 200 H.P.; the specified duty is the delivery of 230 gallons of water per minute against an accumulator pressure of 1,120 lbs. per square inch, with 120 lbs. per square inch steam-pressure, the piston speed not exceeding 240 feet per minute. The steam at 120 lbs. pressure is supplied by five steel Lancashire boilers, each 30 feet long by 7 feet 6 inches diameter; they are furnished with Vicars' mechanical stokers, and have two Green's economisers of 360 pipes together. The coal is brought from the coal store to the stoker hoppers by means of a ladder elevator discharging into a worm conveyor-trough,

which is carried along the wall of the boiler house; this in turn feeds the conveyor extending over the boiler fronts. Coal is delivered to the station either by barge or by road, and is handled by a 30-cwt. hydraulic travelling-crane. Three-cylinder Brotherhood hydraulic engines are provided for actuating the conveyors, stokers, and economiser-scrapers in the boiler-house, and also for working the lathe and drill in the fitter's shop. The two accumulators have rams 18 inches diameter and 23 feet stroke, and are loaded to give a minimum pressure of 1,000 lbs. per square inch at the consumers' machinery. The station having been opened in the present year is not yet working to its full capacity. The number however of machines already connected, and of others for which contracts are pending, is so large that in a few months the four engines already installed will be barely sufficient for the work to be done. The works were designed by Mr. Corbet Woodall, and are in charge of Mr. Frederic M. Evanson, Engineer and Manager.

MANCHESTER CORPORATION GAS WORKS.

Manchester has long enjoyed the reputation of being one of the best lighted cities in the kingdom, and the present gas works are extensive, important, costly, and the property of the citizens. In 1805 the first building was lighted with gas in Salford, and in 1807 the Police Commissioners of Manchester affixed a public lamp opposite their premises in Police Street; from that date to this Manchester has been prominent for the extent and success of its gas manufacture. Manchester men have contributed largely to the successful development of gas, eminent among them being the chemist, Dr. Henry, who was early in the field as an analyst; Murdoch also secured here one of his most brilliant successes. The gas meter was partly originated and successfully completed in this city by Mr. Clegg; and a former officer of health in Manchester, the late Mr. John Leigh, did much to develop the utilization of the products of tar for the production of the beautiful colours now so familiar. Manchester was also the first municipal authority to

obtain powers in 1824 for the manufacture and supply of gas; and since that date the work has been increasingly successful. While on the one hand the convenience of the public has been promoted, on the other large contributions have been made to the city funds, and the rates have been correspondingly reduced. The gas works were transferred to the Corporation on 28th June 1843 by the Commissioners of Police, who had previously had charge of the lighting of the town, and who had been instrumental in obtaining the gas act of 1824, authorizing them to establish gas works.

The Corporation now possess four extensive gas stations, Gaythorn, Rochdale Road, Bradford Road, and Droylsden. At the first three, coal and cannel &c. forwarded by the Manchester Ship Canal can be delivered by rail from the docks; at Droylsden the Ashton and Oldham Canal runs alongside, and supplies of coal and cannel are received thereby daily.

Gaythorn gas station stands on nearly nine acres, and has two retort houses capable of carbonizing 430 tons of cannel and coal daily, producing 4,250,000 cubic feet of gas. The retorts in No. 1 house with 280 mouthpieces are charged by hand; whilst those in No. 2 house with 492 mouthpieces are charged and drawn by Foulis and Woodward's hydraulic machinery, to which is also adapted apparatus for breaking and conveying the coal and cannel. There are seven gasholders with three lifts constructed on the telescopic principle, having a storage capacity of over 6,000,000 cubic feet. The number of men employed varies from 269 to 409. These works have railway siding accommodation, and are in communication with the Manchester Sheffield & Lincolnshire and London & North Western Railways.

Rochdale Road gas station stands on over nine acres, and has four retort houses capable of carbonizing 830 tons of cannel and coal daily, producing 8,500,000 cubic feet of gas. House A with 252 mouthpieces is worked with Foulis' charging machines; House B with 294 mouthpieces is worked with Foulis and Woodward's machines; House C with 280 mouthpieces is worked with West's charging machines; and House D with 304 mouthpieces is worked with Woodward's gas stoking machines. The stack in House D

was reconstructed in 1891 on the generator (cold air) principle; and the stack in House B was reconstructed in 1892 on the regenerator (hot air) principle. There are six gasholders with three lifts, constructed on the telescopic principle, with a storage capacity of 5,000,000 cubic feet. Storage is provided for 32,000 tons of cannel. The number of men employed varies from 410 to 662. These works have good railway siding accommodation, and are in direct communication with the Lancashire and Yorkshire Railway.

Bradford Road gas station comprises nearly fifty-two acres. There are two retort houses capable of carbonizing 830 tons of coal and cannel daily, producing 8,500,000 cubic feet of gas. Gas making was commenced in the first retort house on 16th December 1884, and in the second house on 11th November 1892. The retort settings are constructed on the regenerator principle. No. 1 house with 488 mouthpieces is worked with West's charging and drawing machinery, comprising air compressor, air receivers, air pipes and drums, coal breakers, elevators, and coal hoppers. No. 2 house with 464 mouthpieces is at present worked by hand, but arrangements are being carried out for the use of stoking machinery. There are four gasholders with three lifts, constructed on the telescopic principle, with a total capacity of 6,800,000 cubic feet. A new gasholder tank is being constructed by Mr. James Nuttall of Manchester, for a holder capable of containing 7,000,000 cubic feet of gas. The holder itself is being built by Messrs. Ashmore, Benson, Pease and Co., of Stockton-on-Tees; the outer lift will be 250 feet diameter by 50 feet deep, the middle lift 247 feet diameter by 50 feet, the inner lift 244 feet diameter by 50 feet. The number of men employed varies from 353 to 675. These works have good sidings for railway wagons, and are in direct communication with the Lancashire and Yorkshire Railway; and the Ashton and Oldham Canal runs by them.

Droylsden gas station stands on over four acres. The retort house has been reconstructed, and now contains 30 mouthpieces with settings of inclined retorts, and is capable of carbonizing 40 tons of coal and cannel daily, producing 400,000 cubic feet of gas. A new three-lift gasholder on Gadd and Mason's principle has been

erected to hold 525,000 cubic feet of gas. These works were purchased from the Droylsden Gas Co. in 1869, and then occupied just over one acre. During the last three years more land has been purchased, the retort house has been altered for the adoption of inclined retorts, new buildings have been put up to accommodate the plant required, and a new holder has been erected.

For the distribution of the gas, the length of main pipes laid is 705 miles, and of service pipes 270 miles, making a total of 975 miles. The number of men employed is about 420.

The amount of gas made in 1893 was considerably over 3,600 million cubic feet, and the quantity of cannel and coal carbonized 365,235 tons; 21½ million cubic feet of gas can be produced in twenty-four hours. The price of gas to the consumer is 2*s.* 6*d.* per thousand cubic feet, and the net profit was £64,793, the greater part being handed to the city fund, thus materially reducing the rates. The largest daily consumption of gas, over 22 million cubic feet, occurred on 8th December 1892.

MESSRS. S. AND J. WATTS AND CO.'S WAREHOUSE.

The Warehousing business of this firm was established in Deansgate in 1796 by Mr. John Watts, and was afterwards transferred to larger premises in New Brown Street, where he was joined by his brothers Samuel and James. After a further removal to yet larger premises in Fountain Street, the present warehouse was erected in Portland Street on a site purchased in 1855 by the late Mr. Samuel Watts, and was opened in 1858. The building covers an area of 3,000 square yards, its length being 100 yards, its width 30 yards, and its height 100 feet. The great expanse of roof has a series of bays filled with ground glass, admitting an abundance of light; above it rise four dwarf towers. There are five floors, which with cellar and four towers give an aggregate area of 19,360 square yards or nearly four acres. The several kinds of goods, representing all branches of the Manchester trade, are classified in thirty-two departments, arranged on the successive floors

as follows:—ground floor, hosiery, linens, carpets, flannels, whites, greys, fustians; first floor, merinos, dresses, woollens, ready-mades, dyed goods, Scotch and muslin, worsteds, &c.; second floor, umbrellas, trimmings, fancy haberdashery, bags, satchels, portmanteaus, small wares, stays and corsets, waterproof goods, table oil baizes, boots and shoes, gloves; third floor, ribbons, bandanas, silks, skirts and underclothing, mantles and costumes, prints, fancy flannels; fourth floor, flowers, millinery, lace, sewed muslins, furs, straws. Each department has its own buyer; and the assistant and working staff make up a total of fully six hundred persons.

Another warehouse in Silver Street, formerly used for packing, and rebuilt a few years ago, is a commodious structure of three storeys and basement. It is devoted to the ready-made clothing and shirt departments, and is equipped with the best modern machinery and appliances for these trades, giving employment to upwards of three hundred workpeople.

The adjoining warehouse in Chorlton Street has recently been acquired for the hardware trade; and another in Chorlton Street and Major Street for the shipping business.

MANCHESTER SHIPPING OFFICES AND PACKING CO.'S WAREHOUSE.

This company was formed in 1864 for the purpose of providing offices and ware-rooms for shipping merchants, whose goods they make up, pack, and send to the port whence they are to be shipped. The premises cover about 2,600 square yards, and about 45 shipping merchants occupy rooms in the building. There are fourteen hydraulic presses with rams ranging from 12 to 20 inches diameter, and plaiting machines are used in the process of making up the goods. The whole of the presses, passenger-elevators, hoists, &c., are worked by hydraulic power in connection with intensifiers and accumulators. The building is lighted by the electric light generated on the premises. All classes of soft goods are shipped, varying from canvas to silk, and are packed in materials suitable

for their particular markets. Packages weighing altogether upwards of 25,000 tons are sent away annually to all parts of the world; they vary in weight from 50 lbs. to 30 cwts. each. About 150 workmen are employed.

MANCHESTER FIRE BRIGADE.

The force consists of 89 men of all ranks, residing at seven engine stations. There are fifteen hose-cart escape stations, each with a fireman on duty by day and night, supplied with men from the engine stations; and one hose-cart escape station in Piccadilly has two men by day and two by night. These stations are so distributed that in any place in the city assistance in case of fire can be obtained within a distance equivalent to ten minutes. The whole of the branch stations and the subscribers to the telephone exchange are connected with the chief station by telephone.

The plant consists of eight steamers, three hand-worked engines, six tenders, twenty-three hose-cart escapes, one 80-feet and two 40-feet extension ladders, 13,675 yards of hose, 107 stand pipes, 115 branch pipes, and 27 horses. The city is well provided with hydrants on the constant-service water-mains, which afford a working water-pressure varying from 40 to 100 lbs. on the square inch. By coupling two hose pipes into a single jet, very powerful deliveries can be obtained.

SIR ELKANAH ARMITAGE AND SONS, PENDLETON NEW MILLS.

These mills are situated at Pendleton, near Manchester, and in them are carried on the processes of cotton spinning, dyeing, and weaving. There are 70,000 spinning and doubling spindles, and 1,450 looms. The number of workpeople employed is about 2,000.

MESSRS. RICHARD HAWORTH AND CO., EGERTON, TATTON, ORDSAL, AND THROSTLE NEST MILLS, SALFORD.

These cotton spinning and manufacturing mills are situated on the northern bank of the Manchester Ship Canal and opposite the Pomona docks. The Ordsal dock adjoins the western end of the premises, and when this is completed the mills will have a continuous frontage to the water of over 500 yards. They are of the most modern construction, due regard having been paid to ventilation, sanitation, and lighting; automatic sprinklers are fixed in almost every part for the speedy extinction of fire. The rooms and weaving sheds are lighted in winter by incandescent lamps from electricity generated on the premises. There are upwards of 100,000 spindles and over 3,000 looms, with all other necessary machinery; and the consumption of yarn at the present time amounts to nearly 100 tons a week. The number of workpeople employed is over 3,000.

MESSRS. J. AND N. PHILIPS AND CO.'S WAREHOUSE.

This warehouse was established in 1832 for wholesale home and foreign business. The trade consists chiefly in supplying drapers in the United Kingdom with goods of almost every description. The number of persons employed is about 700.

CO-OPERATIVE WHOLESALE SOCIETY.

This society, whose central offices are at 1 Balloon Street, is the practical result of numerous conferences which were held by the retail stores, with the object of giving effect to the idea of a wholesale agency for joint purchasing. It was registered under the Industrial and Provident Societies Act, 1862, and commenced business 14th

March 1864. The premises in Manchester, which cover considerably more than an acre of ground, comprise the general offices, bank, board room, grocery, drapery, boot and shoe, and furnishing departments; also boiler and engine houses for generating the requisite power to work the numerous hoists, and the electric light by which the premises are lighted throughout. With the object of buying from the producers the society has established six purchasing depôts in Ireland, whose combined shipments of butter and eggs amounted in 1893 to £400,000. It has also purchasing depôts in Hamburg, Copenhagen, Aarhuus, New York, and Montreal; also works at Crumpsall, near Manchester, for the manufacture of biscuits, sweets, jam, marmalade, and dried goods, employing 300 hands, and producing in 1893 goods to the value of £84,000. Shoe works are established at Leicester and Heckmondwike, employing 2,300 hands, and turning out 1,200,000 pairs annually, valued at £287,000. It also has soap works at Durham, a woollen mill at Batley, a clothing factory at Leeds, a flour mill at Dunston-on-Tyne, and a cabinet factory at Broughton, near Manchester. The total capital employed in productive works amounts to about £400,000, the value of goods produced annually to £800,000, and employment is given to 3,500 hands. Distributive branches of the society are established in Newcastle-on-Tyne and London; and sale rooms and depôts are also opened at Leeds, Nottingham, Blackburn, Huddersfield, Birmingham, Northampton, Bristol, and Cardiff. It owns a fleet of six steamers trading between this country and France and Germany. A tea, coffee, and cocoa department is in operation in London, employing over 300 hands and turning out an average of 60 tons of tea per week. In 1872 the banking department was opened, the turnover in 1873 being £1,581,495 compared with £30,000,000 in 1893. The total number of persons employed in 1893 was 5,200. The progress of the society has on the whole been rapid and continuous. The number of members belonging to shareholding societies has risen from 24,005 in 1865 to 873,698 in 1893; the total capital, shares, loans, reserve and insurance funds from £7,182 to £1,779,301; sales from £120,754 to £9,526,167; and net profit from £1,858 in 1865 to £84,156 in 1893.

MESSRS. GALLOWAYS, KNOTT MILL IRON WORKS.

These works, situated close to the Knott Mill railway station, are in a thickly inhabited district on the banks of the Medlock, and are entirely devoted to the construction of steam engines, gearing, hydraulic plant and general engineering work, mostly of a heavy class. In addition to this they make all their own fittings for the large number of boilers which are constructed at their boiler works some distance away. The works were established in 1834 by William and John Galloway, whose sons were introduced in 1856, when the title was changed to W. and J. Galloway and Sons; and the firm was converted into a company in 1889. There are the usual pattern shops, a large foundry with glass roof, traversed by two travelling-cranes and provided with a number of jib cranes. This foundry stands on the site of the previous boiler shop before its removal in 1871. There is a smithy, dealing with fairly heavy work, and machine shops well provided with engineering tools, including a cross planing-machine for planing 25 feet long by 10 feet wide and 10 feet high; also a quadruple-geared lathe with 72-inch centres by 50 feet long and with face plate 10 feet 3 inches diameter. There is also a large erecting shop with travelling and jib cranes for the final fitting up of the work.

In connection with these works there is a small rolling-mill plant with heating furnace and steam-hammer for cleaning and working scrap into rivet iron, as large quantities of rivets are made both for use at the boiler works and for sale. Two of their own boilers fired in the usual way are used for providing steam, also one heated by gas from the forge furnaces, and a "Manchester" water-tube boiler on the plan which they have lately introduced. A twin compound Galloway engine with instantaneous cut-off provides the greater portion of the power for driving the machinery; and there is also a triple-expansion superposed engine for working with 200 lbs. steam, which is the pressure adopted in connection with the water-tube boiler. The number of men employed is about 400.

MESSRS. RYLANDS AND SONS' WAREHOUSES.

These consist of four piles of buildings in Manchester, situated in Market Street, New High Street, Bread Street, and Joiner Street. They are divided into forty-two departments, comprising all classes of textile goods for articles of dress and for the furnishing of houses; the four together employ about 1,200 persons. Their warehouses in Wood Street and Philip Lane, London, employ about 800. The firm was established in 1823; they import almost every variety of article, and from almost all parts of the world. Their most extensive import is raw cotton, averaging from 5,000 to 6,000 tons per annum, of the value of more than £250,000, most of which is spun and manufactured in their own mills. Their other imports from the continent amount to about 2,000 tons per annum. Selling or turning out some 30,000 tons of goods every year, they find fully two-thirds of these are for the home markets, and the remainder for export. As general merchants and shippers of dry goods, and as spinners, manufacturers, bleachers, dyers, and colliery owners, they employ more than 11,600 persons, of whom by far the largest proportion are operatives employed in their various works. Of these there are seventeen, situated chiefly around Manchester as the centre; the principal are the spinning and weaving mills, containing a total of 5,000 looms, with all spinning and preparation of yarns for the same. In the Gorton Mills, near Manchester, are produced grey dacca calicoes, sheetings, twills, and jeanettes; there are 1,550 looms, engines indicating 2,000 horse-power, and 1,600 workpeople. The Gidlow Works, Wigan, producing calico, employ about 1,600 persons, and contain 1,600 looms, with engines of 2,000 horse-power. The Swinton Mills, near Manchester, with engines of 300 horse-power, 700 looms, and 600 workpeople, produce regattas, oxfords, galateas, and special goods. The Heapey Bleach Works, near Chorley, together with their reservoirs, cover 40 acres; the daily consumption of water is over two million gallons, the engines indicate 2,000 horse-power, and 600 persons are employed in the

scouring, bleaching, and dyeing, of calicoes, twills, and sheetings, &c. At Chorley are also works for making floor oil-cloth of all kinds; these employ engines of 250 horse-power, and 200 workpeople. Other works are in Manchester itself, and in Bolton, Crewe, and London.

MESSRS. HULSE AND CO., ORDSAL WORKS, SALFORD.

These works were established in 1852 by the late Mr. J. S. Hulse on his retiring from the firm of Messrs. Joseph Whitworth and Co., after a connection of seventeen years. In 1881 the business devolved on Mr. W. W. Hulse, and has since been greatly extended, having now a floor area of over 8,000 square yards. There are four erecting shops, each provided with 25 to 30-ton overhead power cranes, specially designed by the firm for workshop use, and arranged to command almost the full length and width of each shop. Being glazed all over, these shops are pretty nearly as light inside as out of doors. In addition to the machine and erecting shops there are galleries devoted to cutter and gauge making &c., and other light work.

Some of the largest and heaviest machine-tools in existence have emanated from these works, including horizontal and vertical planing machines up to 100 tons weight; twin-screw lathes up to 100 feet long for turning marine cranks, propeller shafts, cannon &c.; heavy planing machines with tables propelled by twin-screws for machining large armour-plates; marine cylinder-boring machines with self-contained steam engines for boring and facing cylinders up to 12 feet diameter; large milling machines, both vertical and horizontal; vertical lathes up to 30 feet diameter. Special attention has of late been devoted to machines for marine, locomotive, and stationary boiler-work, such as machines for turning the ends of Lancashire and other similar boilers, and boring the circular and oval holes therein; multiple-drilling machines for water-tube boilers for torpedo-boat destroyers, and multiple-spindle boring,

facing, and screwing machines for dealing with various parts of Belleville boilers. The smaller sizes of engineers' tools are also made, such as lathes from $4\frac{1}{2}$ inches centres, planing machines from 18 inches wide, shaping and slotting machines from 4 inches stroke upwards, small milling, drilling, boring, and wheel-cutting machines, &c.

Recently an important addition has been made by the acquisition of the adjacent works and business of Mr. Thomas Gadd, which were established in 1847 for the design and manufacture of machinery for calico printers, bleachers, dyers and finishers, and of steam engines and cranes.

MESSRS. KENDALL AND GENT, VICTORIA WORKS, SALFORD.

These works for the construction of machine-tools are situated on the Salford side of the River Irwell, close to Springfield Bridge. The first portion of the works was built in 1849 when the firm was established, the remainder having been built as the business developed. The buildings, which are mainly of two storeys, have on the ground floor planing shops, turning, smiths' and erecting shops for heavy tools; the first floors are reserved for the construction of light machines and some parts of heavier machines. also for general offices, drawing offices, pattern shops, &c. The continuity of the various processes to which parts of machines are subjected is carried out so far as the arrangement of the works will allow. Heavy castings are first dealt with by a series of planing machines varying in length from 4 feet to 38 feet, and in width from 2 feet to 7 feet. They are of the usual kind: but in some of the most recent the tables are traversed on flat slides, in order to diminish friction and to allow of heavier cutting. whilst the cutting and return motions are driven by separate belts. For planing the sides and ends of heavy pieces a highly useful type of side planing machine is employed, the work being fixed on a large foundation plate. The boring machines, which are of the universal

kind as best adapted for dealing with the ever-changing designs of machine-tools, are mounted on planed foundation-plates in the erecting shop for heavy tools. The turning shop for heavy tools contains a great variety of lathes, among which the duplex shaft-turning, the screw-cutting, and the pulley-turning lathes are particularly interesting. Among the lighter lathes on the first floors the method of turning studs and screws from the solid bar is largely practised; and among other machines on these floors are a number of milling and other machines for the making, hardening, and grinding of milling cutters of all sizes, and also for the grinding and finishing of hardened steel spindles and other work where great accuracy is required.

A prominent feature of the works is the universal employment of tool-holders on both heavy and light machines, so that the workmen never need to leave their machines for the grinding of tools, as these are supplied to them in quantities ready ground to correct cutting-angles which cannot be deviated from. Another feature is the extensive adoption of milling for the finishing of work formerly done on shaping and slotting machines. The number of men employed is about 250.

MESSRS. WILLIAM MUIR AND CO., BRITANNIA WORKS, STRANGEWAYS.

The business of this firm was established by the late Mr. William Muir in 1842; the present works were built in 1851, and have gradually extended until nearly all the available ground is occupied. The trade carried on is the manufacture of machine-tools for marine, general, and locomotive engineers, boiler makers, gun and small-arms manufacturers. The number of persons employed is about 400.

MESSRS. SMITH AND COVENTRY, GRESLEY IRON WORKS, SALFORD.

This firm commenced business in Chapel Street, Salford, in 1859; and in 1861 the first portion of the Gresley Works in Ordsal Lane was built. They were among the first to adopt the principle, now more commonly in use among engineers, of building an open erecting-shop lighted from above, commanded by travelling cranes, and having galleries and machine-shops flanking and open to it on either side. A further enlargement of the works took place in 1873, and again in 1876, when the manufacture of twist drills was taken up; yet again in 1884, and in 1890, when a new boiler-house was built, with steel boiler having mechanical stoking and smoke-consuming apparatus, and also an economiser and case-hardening furnace. In 1891 new machine-shops, pattern-making shops, and stores, were constructed; no timber was used in their erection, the materials being rolled-steel girders, brick, masonry, and concrete. The pattern-shop and pattern-stores, besides being fire-proof, are provided with Grinnell sprinklers. In making these additions, a street was closed up and a portion of the buildings erected over it. In these premises a hydraulic elevator is at work, for carrying workmen, and loads up to half-a-ton weight, up or down from floor to floor. For connection with the street, a Barker's hoist is employed for lifting up and landing, on any of the four floors or on the roof, any pieces of work not exceeding two tons. This new extension adds one-third more floor-capacity to the old works, and provides space for the employment in all of 500 workmen. In 1893 new general offices, drawing office, stores and tool-room were built, this block of buildings also being fire-proof.

At these works some of the most advanced machine-tools may be seen in operation. Many milling machines of different kinds have been designed and manufactured since 1876, and have been found most efficient for machining even the large parts of stationary and marine engines, locomotives &c., and for numerous other purposes. Their application to the heavy classes of work has in

most cases been very efficacious, and the milling of large pieces has been done in England at an earlier period than in America, where milling has usually been confined to the production of small articles. A large number of twist drills are manufactured, the number made here in 1891 being 134,940. A severe test is applied to each taper-shank twist-drill, by drilling with it through wrought-iron or wrought-steel in a drilling machine having a coarse feed; each drill is required to stand this test satisfactorily before it is allowed to be sent out of the works.

At the present time some large boring and turning mills, to admit 12, 14, 16, and 18 feet diameter, are in course of manufacture; several rather smaller machines of this class have already been constructed. A large cylinder-boring machine, which will do four operations at once, is now approaching completion. The works are also engaged in the manufacture of cylindrical gauges as standards of measure, which are guaranteed correct to 1-25,000th of an inch. Another class of gauge for workshop use is also made; these are accurately got up and tested not to deviate more than 1-5,000th of an inch. An ingenious and novel lathe may be seen at work, turning hexagonal and square pieces of brass, suitable for steam and water fittings. The radial and other drilling machines in progress, and some at work, are of improved design, adapted to save time in drilling and tapping holes, and to produce the most accurate work. A double brass lathe, worked by one attendant, does the boring out of the internal taper part of the barrel of a steam or water tap, while at the same time its taper plug is being turned externally to exactly the same taper; not only therefore is the workmanship accurate, but the work is done with great rapidity. Lathes of great delicacy are at work producing the most accurate turning; also highly finished grinding machines, which grind to the accuracy of 1-40,000th of an inch: these two kinds of machines are working in combination with each other. A double sawing machine is used for cutting off dies, chasers, and other cutters to given lengths and to any angle. By means of special machinery bevel and mitre wheels are cut with absolute mathematical accuracy, and many milling machines can also cut spur wheels and pinions.

Among the earliest inventions at these works was a chasing lathe, which effected a complete revolution in the system of cutting screw-threads. With the old screw-cutting lathe, there was no gauge or stop to determine the exact diameters produced, and many traverses of the tool had to be taken over a bolt before it was completed. But in the chasing lathe a number of tools are arranged concentrically, and cut a screw by one single run over it, taking twelve to fifteen shavings off the screw simultaneously, and thereby increasing sixfold the production of chasing. Originally these lathes were all made with centres, but latterly they are mostly provided with hollow and open spindles, through which bars of metal are protruded; and by the capstan-rest method, which was soon afterwards introduced, set-screws, studs, pins, &c., are produced and cut off direct from the bar, thus saving the expensive item of forging, centering, driving by carriers, &c. Pointing, ending, and sliding are also done economically by these lathes. Other early inventions were a system of toolholders and cutters to take the place of forged tools; and with this system the whole of the planing, turning, shaping, and the greater part of the slotting, are done here with great advantage, not only in the quality of work produced, but also in the rapidity with which it is accomplished. The costly forging and constant repairing of tools are thus entirely done away with, and each machine, which is daily supplied with a quantity of ready-ground cutting-tools, is enabled to be kept going without cessation, except for changes of work; great economy is thereby effected. Adjustable parallel blocks for use in many machine-tools are also being manufactured. The accurate workmanship in producing the Pearn lightning tappers by special tools and appliances is worthy of notice.

SALFORD CORPORATION GAS WORKS.

The Regent Road Works and the Liverpool Street Works are situated on either side of the London and North Western Railway to Liverpool, and are connected by a foot-bridge. They were commenced in 1858, and cover an area of $12\frac{1}{3}$ acres.

At the Regent Road Works there are two retort-houses, containing together 212 through retorts, capable of carbonizing 237 tons of coal, and producing 2,370,000 cubic feet of gas per day. In the larger of these two houses the work of charging and drawing the retorts is effected by machines actuated by hydraulic pressure. The coal for use in this house passes direct from railway trucks into coal breakers underneath, where it is broken to a convenient size. It is then elevated and conveyed to the charging machines in the retort house by Woodward's conveyors, which tip the coal into hoppers on the charging machines; and from these it is fed into the scoops which put it into the retorts. The average time taken by the machines in drawing the coke out of a retort and putting in a fresh charge of coal is one minute.

The hydraulic power is obtained by means of a pair of high-pressure horizontal engines, with cylinders 12 inches diameter by 15 inches stroke, driving two double-acting pumps, each pump $6\frac{1}{2}$ and $4\frac{1}{2}$ inches diameter. The hydraulic pressure employed in the machines is 175 lbs. per square inch. The coalbreakers and conveyors are driven by two high-pressure horizontal engines, with cylinders 12 inches diameter and 18 inches stroke. The machinery was designed by Mr. William Foulis, gas engineer to the corporation of Glasgow, and supplied by Messrs. Adam Woodward and Sons of Manchester.

There are two pairs of horizontal reciprocating gas-exhausters, each pair capable of passing 80,000 cubic feet of gas per hour, driven by high-pressure steam engines with cylinders 9 inches diameter and 20 inches stroke. The crude gas is first passed through a condenser, consisting of a number of horizontal pipes 10 inches diameter, of which a portion are exposed to the air, and the remainder immersed in water. It is here cooled to the temperature of the atmosphere, and then passes through two Livesey washers, where the tar is removed. From these it is forced through three tower-scrubbers 50 feet high and 12 feet diameter, to remove the ammonia. It then passes through six purifiers 30 feet by 30 feet, filled with lime and oxide of iron, where the remaining impurities are taken out. From these it goes through the station meters into the gasholders.

There are two telescopic gasholders; one 100 feet diameter, with two lifts each 24 feet high, having a total capacity of 400,000 cubic feet; and the other 150 feet diameter, with four lifts each 30 feet high, having a total capacity of 2,000,000 cubic feet.

The Liverpool Street Works have two retort-houses, the first containing 192 ⌓ retorts 20 feet long by 22 inches wide and 16 inches high, heated by regenerative furnaces. They carbonize 264 tons of coal, and produce 2,640,000 cubic feet of gas per day. The coal for these retorts is supplied in railway trucks, which are lifted by two 20-ton hydraulic wagon-hoists on to elevated railways over the coal stores. There are two pairs of double-acting hydraulic pumps, each of the four pumps being $3\frac{3}{8}$ and $2\frac{1}{4}$ inches diameter and 18 inches stroke, driven by high-pressure horizontal steam-engines with cylinders 12 inches diameter and 18 inches stroke. The hydraulic machinery and engines were manufactured by Messrs. Tannett Walker and Co. of Leeds.

The other retort-house has just been completed. It is designed to contain four benches of 72 retorts each, but at present only one bench is erected. These retorts are built at an angle of 32°, and will be charged with coal from the upper end by gravity. A considerable saving in labour is thereby effected. The coal falls from railway trucks into a coalbreaker underground, and after being broken is lifted by an elevator into large hoppers, placed above the retort bench. A smaller hopper which travels on rails in front of the retort bench conveys the coal from the large hopper to the retorts as required. In emptying the retorts, the lid at the lower end is opened, and the coke slides out into barrows placed beneath. The coalbreaker and elevator are driven by a 14-H.P. Otto gas engine, with cylinder $11\frac{1}{2}$ inches diameter by 1 foot 9 inches stroke, made by Messrs. Crossley Brothers of Manchester. The elevators, conveyors, and coalbreaker were supplied by West's Gas Improvement Co. of Miles Platting. When fully equipped this retort-house will carbonize 400 tons of coal, and produce four million cubic feet of gas per day. There are two pairs of rotary gas-exhausters made by Messrs. Laidlaw and Sons of Glasgow.

Each pair is driven by a high-pressure steam-engine with cylinder 16 inches diameter by 22 inches stroke, and is capable of passing 200,000 cubic feet of gas per hour. There is an annular vertical atmospheric condenser, and a vertical tubular condenser for cooling the gas by water. There are two rotary washers, and four tower-scrubbers, the latter 12 feet diameter and 60 feet high. The purifiers are six in number, 24 feet by 24 feet; their lids are lifted by hydraulic pressure.

The ammoniacal liquor produced at all the works is converted into sulphate of ammonia by means of a Feldman sulphate apparatus; last year 14,000 tons of liquor were treated, and 1,250 tons of sulphate made.

The water required for cooling and washing the gas, working the hydraulic machinery, quenching coke, &c., is obtained from an artesian well, which was sunk on the works by Messrs. Mather and Platt of Salford. The well is 500 feet deep, and varies from $26\frac{1}{2}$ to 15 inches diameter. The pump is 12 inches diameter by 36 inches stroke, and is driven through helical gearing by a horizontal steam-engine having a single cylinder 12 inches diameter by 16 inches stroke. The well yields about 10,000 gallons of water per hour.

SALFORD CORPORATION SEWAGE WORKS.

These works occupy a site of 34 acres, and treat an average of 10 million gallons of sewage per day, from a population of about 200,000. About 85 per cent. of the sewage is brought by a low-level intercepting sewer of 8 feet 9 inches diameter at the outlet, and the remaining 15 per cent. comes by a 4-feet high-level sewer and some small sewers. The low-level sewage is raised about 30 feet by pumping engines, made in 1883 by Messrs. James Watt and Co., but recently improved materially under the direction of Messrs. John Hopkinson and Son. There are two sets of almost duplicate engines, vertical compound, with double-acting rams, each capable of pumping 14 million gallons per day. The four boilers and the economisers are of the usual Lancashire type.

The sewage is treated in twelve tanks, having a total capacity of 5 million gallons; six of the tanks are generally receiving the sewage, while the other six are having the sludge removed from them. The effluent from the tanks is utilized to work turbines for driving the mixing machinery in the lime house, the works having been arranged for the simple and cheap lime precipitation process.

During the past five years extensive experiments have been carried on at these works, about twenty-five processes of sewage treatment having been carefully tested, either in small tanks specially prepared, or on the whole flow of sewage. Some experiments are still in progress at the works, and some of the tanks from former experiments are used for experimental sewage filtration through sand and cinders, with special means of aeration.

The sludge intercepted from the sewage, and thus kept out of the Irwell, amounts now to about 140,000 cubic yards; at present it remains on the site, pending its shipment to sea by a proposed sludge steamer like those used by the London County Council. A complete scheme for alterations and additions to the works, including filtration of the sewage effluent, has been prepared by Mr. Joseph Corbett, Borough Engineer, and is now under consideration by the River Conservancy Committee of the Salford Corporation.

MESSRS. BEYER, PEACOCK AND CO., GORTON FOUNDRY.

These works are situated alongside the Manchester Sheffield and Lincolnshire Railway at Gorton. They were founded in 1854, and at the present time occupy nearly 22 acres. The general offices are handsome and lofty, and the drawing office is exceptionally capacious, well fitted and well lighted. Electric light is employed throughout this department in conjunction with gas, both of which can be used at once or separately. Electric light is also used in the pattern-

making shop and the pattern stores. Connected with the drawing office are photographic and model rooms, including a tracing-room, in which girls are exclusively employed. The works are arranged in three main avenues running north and south, the shops standing west to east across each avenue, with a large block of buildings to the south.

In the northern end of the western avenue are gas-fitting and steel-melting shops, and a brass foundry containing twelve furnaces. The next building is the iron foundry, a lofty structure in two bays, each 143 feet long, which is the length of all the buildings in this avenue. In each bay there is an overhead power-traveller of 10 tons, and in one of them an overhead 5-ton crane also. Besides these there are various jib-cranes ranging in power from 1 to 3 tons, worked by hydraulic pressure, which command the entire area. Leading from this department is the tool shop, also in two bays. This contains some exceptionally large and heavy tools, including a planing machine, designed to take the largest locomotive-frames that are made. The tool erecting shop adjoining is in one bay, and is provided with a powerful 25-ton overhead travelling crane. A room forming a wing to this bay is set apart for keeping templates of all kinds; and beyond it is a house containing a 50-ton Wicksteed machine for testing the materials used. The frame machine-shop consists of four bays, the first two being provided with machinery for preparing the frames for the subsequent fitting, which is performed in the other two. Among the machines in this shop are slotting machines fitted with three heads, and making a 12-inch stroke; and hydraulic machines for riveting. Next is a shop for locomotive erection, in a single bay 386 feet long. Lifting power is provided by one 25-ton and one 40-ton overhead traveller, which span the entire width of the section.

In the central avenue the shops are 163 feet long; and the western erecting shop being coupled to the central by a length of 80 feet, the two powerful travelling cranes are thus enabled to serve the whole 386 feet length of erecting shop commanded by them. The floor of this shop is laid with six different gauges of railway, besides an 18-inch gauge line, which runs through

all the shops and yards. The four bays which follow comprise the machine-shop, two being devoted mainly to wheels, and two to cranks &c. The travelling and jib cranes are driven by ropes. All the wheels and crank-pins are forced on by hydraulic power. The cylinder shops in two bays are succeeded by an erecting shop for tramway engines, and the latter by shops for wheel cutting and grinding.

The pattern-making shop and pattern stores at the northern end of the eastern avenue are on two floors, and are lighted by electricity from the adjoining electric-lighting house. The bays in the eastern avenue are all 123 feet long, and the twelve following the pattern department are occupied with the general smithy and boiler erecting and machine shops, in which hydraulic riveters are extensively used, and most of the flanging is also done by hydraulic power.

The southern block of buildings comprises an extensive forge, wheel-making and case-hardening shops, in three bays 164 feet long. In the wheel-making shop there are nine steam-hammers, ranging up to 6 tons. The west section of the southern block, comprising three bays, is given up to the fitting and erection of tenders, tanks, &c.; here hydraulic and steam riveters are almost exclusively used. Two separate buildings about 270 feet long, provided with an overhead traveller, are used for painting, packing, stores, &c.

In addition to locomotives, all kinds of tools required by locomotive and ordnance builders are manufactured here. Amongst the locomotives designed and constructed by the firm may be mentioned the large engines for the New South Wales Government lines and the Mersey Tunnel Railway, for both of which unusual power is required; in the latter case the gradients are from 1 in 27 to 1 in 30, up which a load of 150 tons has to be hauled. About 2,000 men are employed at the works, and from 150 to 200 engines can be turned out in a year.

MANCHESTER SHEFFIELD AND LINCOLNSHIRE RAILWAY WORKS, GORTON.

These works occupy about 50 acres, and comprise the locomotive and carriage and wagon workshops, together with a large running shed. Entering by way of the Gorton Station, the boiler shops are first approached. They cover an area of about 27,350 square feet, and in them all the flanging, planing, riveting, &c., are done. The boiler erecting shop has a 15-ton overhead travelling-crane worked by rope power; a large plate-edge planing machine, which will also face smoke-box tube-plates and fire-hole rings; punching machines, &c.; and a multiple drilling machine specially made for roof stays, with a milling machine also arranged for the same articles. The copper stays are all chased in this shop. Adjacent thereto is the boiler mounting and tube shop, where all the brass fittings, domes, safety-valves, &c., are faced and studded on, ready for testing previous to the boilers being sent into the erecting shop. Under the same roof as this shop is the tender shop, where tenders are built and repaired; it has a 25-ton overhead travelling-crane, worked by rope power from a wall engine. These two shops together comprise about 30,600 square feet.

Outside the boiler shop are the brass foundry and the forge. Here steam for the steam hammers is generated by means of vertical boilers. The smithy, which is close by, is a circular building with fires all round, and was the original running shed. Adjoining the boiler shop is a heavy turning and machine shop, which covers an area of about 48,200 square feet, and in which all crank and straight axles are turned, hopped, slotted, and bolted, wheels and tires turned, wheels pressed on to axles, frames slotted, drilled, and mounted, cylinders bored and otherwise machined, connecting-rods, coupling-rods, and all motion-work made and repaired, principally by milling machines. Wrought and cast-iron horn-blocks and brass axle-boxes are here machined and prepared for the erecting shop. Part of the shop in which the wheels, tires, and frames are dealt with is fitted with a 5-ton and a 15-ton overhead

travelling-crane, worked by rope power from wall engines. On each side of the turning shop is a gallery carried on the same columns as those which support the roof, and on which are girders for a 10-ton rope-power crane. On this gallery all the brass-work, pins, bolts, studs, and other light articles are manufactured. The whole of this shop is driven by wall engines; this is found to be convenient, in case urgent repairs are necessary and only a portion of the shops are required to be worked for the purpose. At one end of the turning shop on the ground floor old tires are taken off and new tires shrunk on wheels by means of a ring jet, through which gas and air pass for heating. At the other end is the grinding shop, which is driven by a 20-horse-power gas engine.

The new erecting shop is 480 feet long by 250 feet wide, made up of five spans, each 50 feet. Each bay contains three runs, and two 30-ton rope-driven cranes. Line shafting passes through each centre line of columns for cylinder boring, valve facing, and other purposes. The power for driving the cranes &c. in this shop is given off from single-cylinder engines, bolted to the columns supporting the roof. A convenient portion of this shop is partitioned off and divided to accommodate coppersmiths, tube-brazing furnaces, spring smiths, motion washing, joiners, and locomotive painters. A few yards distant is the iron foundry with three cupolas. Here the locomotive castings, together with the chairs, &c., required for the permanent way, are manufactured; and in close proximity is the permanent-way shop, in which are manufactured all points, crossings, turntables, buffer-stops, water-columns, &c. In the same block of buildings are the drawing office, pattern shop, and pattern stores.

Near these buildings are the carriage and wagon building and repairing shops, in which the bulk of the carriage and wagon stock is built and maintained. These shops are replete with all necessary wheel and axle lathes, hydraulic press, the most modern wood-working machinery, smithy, &c.

Near the foundry is the principal running shed in this district. It has twenty roads, each capable of accommodating six large engines and tenders, with space between each for cleaning &c.

These running sheds cover about 83,700 square feet, and are fully equipped. Here is kept the breakdown train, which consists of a 20-ton steam travelling-crane and three tool-vans fully equipped, ready for any emergency. In this yard also is a set of engine balancing tables, made specially for the Liverpool Exhibition, by means of which the exact weight upon each engine and tender wheel is noted and registered. All engines, new or repaired, on coming out of the shops are brought over this table and adjusted, before being put into service. Adjacent to the running shed are large and commodious carriage storage and washing sheds. At Gorton also, though divided from the main works by a street, are situated the canal and gas works, large schools for the workmen's children, library and reading room. The rolling stock comprises 718 engines, 1,105 carriages, and 17,166 merchandise trucks. The chief locomotive engineer is Mr. Harry Pollitt.

MESSRS. JOSEPH ADAMSON AND CO., BOILER WORKS, HYDE.

These works were established in 1874 for the construction of high-class steam-boilers, by the present proprietor in partnership with Mr. Henry Booth, who retired in 1887. They cover about half of a plot of ground of about four acres, closely adjoining Hyde station on the Sheffield and Midland Railway, with which they are directly connected by a private siding. They have from time to time been gradually extended to cope with increased trade, and with the heavier weights called for in boiler work during recent years.

In 1883 a new step was taken by the erection of a special shop, 200 feet long by 45 feet span, to contain a 500-ton hydraulic flanging-press and its necessary dies, which latter by the growing requirements of the trade have already accumulated to the amount of upwards of 400 tons. This flanging department is engaged, in addition to the special flanged work required in the works, in pressing and flanging plates sent in by other boiler-makers. In

connection with the press is a hydraulic accumulator with 12-inch ram and 20 feet stroke, loaded with about 90 tons of pig-iron, and supplied by a set of quadruple fly-wheel steam-pumps, arranged to stop and start automatically according to the position of the accumulator ram. This hydraulic power is also used throughout the works for actuating the riveting machines, cranes, and also a smaller press. The pumps are situated in an engine-house, built close to the boiler-house ; and under the same roof is intended to be placed a series of engines and dynamos forming a central station for the distribution of power and light throughout the works. The beginning of this installation is represented by a 50-H.P. Belliss high-speed engine, directly coupled to a Siemens dynamo running 500 revolutions, which at present is employed only in furnishing the power for the travelling cranes.

The boiler shop proper consists of four bays, each 45 feet span and 200 feet and upwards in length. One end of each bay is adjacent to the railway and sidings, while the offices, stores, &c., are situated at the opposite end of the shops.

The first bay, which may be called the shell shop, contains amongst other tools a plate-edge planing-machine capable of planing plates up to 30 feet long by 6 feet wide on both side and end at one setting, while by carrying the plate forward an indefinite length can be reached. Also two boiler-shell drilling machines, of ten and eleven drills each respectively, arranged to drill both the circular and longitudinal seams. Also a powerful horizontal turning machine, capable of edging plates up to 10 feet diameter, and up to 4 feet deep if required, with an additional boring head for cutting out the flue-holes, and the oval holes for manholes.

The next bay is occupied principally as a fitting shop, and is equipped with a number of engineers' tools, such as lathes, radial drills, slotting, screwing, planing, milling, and grinding machines. The end next to the railway is occupied by punching and planing machines, and a small set of bending rolls, all of which are employed in preparing the flue plates for the subsequent operations in the smithy. The opposite end of the bay is fitted up with the necessary plant for a pattern shop.

The third bay, which may be called the erecting shop, is 30 feet high to underside of roof principals, and is almost entirely roofed in with glass, like the two previous bays. This shop is equipped with three fixed riveters, situated under a brick riveting tower 60 feet high, which on the side next to the shop is open for the full width of 45 feet, the wall on this side being carried by a box girder 33 feet from the floor. There are also portable riveting machines slung from cranes, one being worked by compressed air, which are chiefly used in riveting the ends and flues into boilers. In this operation every rivet on the front ends of Lancashire boilers, inclusive of those connecting the flues to the end plates, is here closed by machinery; and throughout the work a preference is given to machine-riveting on account of its greater reliability than hand work. In this shop is also a range of pipes from the receiver of the air compressor, fitted with taps at intervals for the attachment of pneumatic caulking tools. There are also two or three rivet-heating furnaces, fired with oil in place of coal, in which the air supply is heated by the waste products of combustion.

The fourth bay is occupied by the smithy, at the lower end of which is situated the plant specially designed for drilling and turning the flanges and caulking strips for the internal flues of the boilers.

The two bays in which the heaviest weights have to be handled, that is the shell and erecting shops, are well equipped with power travelling cranes. There are also in course of construction in the works three travelling cranes for the shell shop, which are to be driven by electric motors; and alterations with the same view are in progress for two other cranes for the erecting shop, thus making five electric travelling-cranes in all for the two bays. It is considered that the output of a shop depends more directly on the efficiency of its lifting appliances than upon the actual speed of the machines doing the work.

The whole of the plant is arranged as far as practicable to save labour in handling the materials. The boiler shell-plates for instance are unloaded direct from the railway trucks in the shell shop, and are handled by overhead travellers throughout all the operations of planing, bending, drilling, &c., until the rings are

finished ready to be rolled across to the riveting tower. After being hoisted up in the tower by power-driven crabs for the purpose of riveting, they are lowered down into the shell shop, where the travelling cranes again take charge of them during the various stages the boiler has to go through, before it is completed for the hydraulic test. This test takes place close to the railway trucks, upon which the boiler is then lifted for proceeding to its destination. In ordinary times about 200 hands find employment at these works.

MESSRS. ASHTON BROTHERS AND CO., CARR FIELD MILLS, HYDE.

These mills have been built at various times from the beginning of the present century. The older mills are driven by compound engines with steam at 80 lbs. pressure, and the new mills by a pair of compound engines of 1,000 horse-power of the Corliss type, and two sets of triple-expansion engines, each 500 horse-power, all rope-driving, made by Messrs. Goodfellow, Hyde. The boilers are of steel, 30 feet by 8 feet diameter, carrying a pressure of 150 lbs., and made by Messrs. Joseph Adamson and Co., Hyde. The new mills are lighted electrically by about 1,000 incandescent lamps, put up by Messrs. Stanley and Davies, Hyde. There are 111,350 spindles and 2,302 looms, employing 1,650 workpeople ; the average production per week is 567,000 yards of calico, weighing about 130,000 lbs. or 58 tons.

MESSRS. F. W. ASHTON AND CO., NEWTON BANK PRINT WORKS, HYDE.

These works, situated on the Cheshire side of the river Tame, were established by Messrs. Ashton eighty years ago ; since 1857 they have been worked by the present proprietors. The works were originally laid out for block or hand printing, combined with five printing machines. The styles produced were then chiefly black and

purples, better known as lilacs. Under the present proprietors extensive alterations and improvements have been made to meet the demand for better-class goods and variety of styles. There are now thirteen printing machines, hand printing having been superseded some time ago ; they range from single colours to twelve colours, with improved drying appliances. As there is now a large trade in "discharge" styles, extensive preparations have been made for Turkey red and indigo blue dyeing, with their necessary accompaniments of open soaping and raising arrangements. The bleach works which were built in 1850 are on a scale equal to the other portions of the works. The cloth is received in the grey, and is completed on the premises, including packing for the market. The number of workpeople employed is about 350. The management of the works is in the hands of Mr. James Ashton, eldest son of Mr. F. W. Ashton ; and the city warehouse at 59 Portland Street is managed by Mr. T. Parkinson, one of the members of the firm.

MESSRS. NASMYTH, WILSON AND CO., BRIDGEWATER FOUNDRY, PATRICROFT.

These works had their origin in one of the flats of an old mill in Dale Street, Manchester, where Mr. James Nasmyth, founder of the firm, commenced business in 1834 as a mechanical engineer and machine-tool maker. Thence he removed in 1836 to a timber workshop at Patricroft, near the Bridgewater Canal and the Manchester and Liverpool Railway, more substantial buildings being afterwards substituted, which form part of the present works. Shortly after the establishment of the works at Patricroft, the great improvements made in ocean navigation called for larger engines, for which in consequence much larger forgings were wanted. For producing these he invented the steam-hammer in 1839, and in 1842 commenced making steam-hammers of all descriptions and sizes. In 1843 Mr. Robert Wilson joined the firm, and introduced the self-acting motion, by which the old form of hand gear for working the hammer was entirely dispensed with.

The smithy contains thirty fires and several steam-hammers, all pieces of work being blocked or stamped where possible. In the forge the large hammer "Thor," put up by Mr. Nasmyth about forty years ago for forging guns, is still in use for forging cranks and shafts up to 10 tons weight and 36 feet long. The self-acting motion originally fitted to this hammer has been removed and replaced by the simple circular balanced valve invented by Mr. Wilson, by which the hammer is worked with the greatest facility. The boiler shop is laid out for modern boiler making; all plates are planed on the edges, holes drilled mostly in position, and nearly all riveting done by hydraulic machinery. In the new part of the moulding shop are four 30-ton jib cranes, so arranged at equal distances from a centre that each can carry a suitable ladle for casting large presses and hammer frames; here Mr. Nasmyth's safety ladle is still working, nothing better having as yet been designed. In the heavy machine shop the machinery is being replaced by modern tools. The shop is warmed by cast-iron pipes coiled round the columns, through which steam passes; these pipes have been fixed here for nearly fifty years. In the middle machine-shop the crane gantries are slung from the roof, for allowing the shop cranes to travel well over and clear of the machines and driving gear; a second bay alongside is arranged in the same manner with a lighter crane for the lathes. A line of railway runs all round the works; and a large 40-ton crane travels the length of the yard, and lifts heavy weights, that cannot go by rail, into barges on the old Bridgewater Canal, now taken over by the Manchester Ship Canal.

Across the yard is a massive building of five storeys, each of unusual height, reached by a flight of stone steps running round inside a tower at the north-east corner. The two top storeys are filled with patterns. The second floor is the pattern shop, containing many labour-saving contrivances for woodwork. The first floor is the light tool room, where all brass work and templates are made; it contains many new tools, including copper stay and stud machines of the latest design, by Messrs. Kendall and Gent; also a wheel-cutting machine, made by Mr. Nasmyth about forty years ago

for cutting iron or brass toothed-wheels. The ground floor is the general erecting shop, where hydraulic presses 80 feet high can be erected, the cylinders going into a well 25 feet deep; here also large stationary engines, hammers, cranes, and machine-tools are fitted up. The general work is kept quite distinct from the locomotive work, which is carried on in an adjoining shop, with its own machine-shops. Here the first slot-drill, invented by Mr. Nasmyth about forty-three years ago, is still in use; and near it is an old milling machine made about the same time, though not now used, having been superseded by more modern tools on the same principle. In another small machine-shop are some of Mr. Nasmyth's original shaping and slotting machines, working alongside others by Muir, Whitworth, &c. In the offices are drawings of the first locomotives made at these works in 1841. About forty locomotives are built in a year, all parts being made to templates and gauges so as to be interchangeable. In general work about twenty hydraulic presses and engines are turned out in a year, besides steam hammers, stationary engines, tools, and sundries, making altogether a total of about 3,000 tons of finished work. The number of men employed is over 500.

MANCHESTER CREMATORIUM.

This crematorium, of which the Duke of Westminster is the president and Mr. Henry Simon of Manchester the chairman, is situated alongside the Manchester southern cemetery on the Barlow Moor Road, and is within one mile of the Chorlton-cum-Hardy station on the Cheshire Lines Railway. It was built in 1892, and consists of a hall or chapel, and a separate contiguous chamber containing the furnace. Columbaria for the reception of urns and memorial tablets are provided in arched recesses on the inside and outside of the principal walls of the building. The hall is about 50 feet long by 25 feet wide and of proportionate height. In the centre of the wall opposite to the principal entrance is placed the aperture leading to the furnace, which in the separate space occupies

basement and ground floor. A vestry or record room, and a retiring room, lavatories, &c., are situated at the back of the hall, which is flanked on either side by open arched colonnades raised above the level of the ground, protecting the columbaria in the outside wall. Dignity is given to the main entrance to the hall by means of a lofty arched porch, from which steps connect on either side to the outer colonnades and columbaria. Draught is supplied to the furnace by a chimney hidden in a tower, which gives the building the appearance of a church. It is constructed throughout in terra cotta, and the style of architecture resembles that of some of the oldest churches in Lombardy and Venice. The general arrangement and details of the furnace are from the plans of Mr. Henry Simon, who personally superintended its erection. It is so constructed that the raw fuel does not come in contact with the body; the coffin is noiselessly introduced by invisible machinery. Coke or Welsh anthracite coal is used for the production of the gas; and the cremation is absolutely smokeless. The time of cremation of each body is about seventy-five minutes on an average; and since the opening about sixty cremations have taken place. The total cost of the building and furnace was about £7,000.

MESSRS. YATES AND THOM, CANAL FOUNDRY AND VICTORIA BOILER WORKS, BLACKBURN.

These works were established in 1826, and at present give employment to about 800 men, and cover about eight acres. They produce steam-boilers, stationary engines on the simple, compound, triple and quadruple-expansion principle, with Corliss and other valve-gear, pumping engines for waterworks, blowing engines, mill gearing, and general engineering work. The engines range up to 10,000 I.H.P. The shops are well laid out for dealing with work of the heaviest class, and are fitted with the most modern machine-tools and labour-saving appliances.

LION COTTON SPINNING MILL, ROYTON, NEAR OLDHAM.

This mill is situated near Royton station on the Lancashire and Yorkshire Railway, and is one of the best examples of a modern Lancashire cotton mill. It has six storeys, is 355 feet long and 129 feet broad, and contains 107,000 mule spindles with the necessary carding and other preparation machinery, which have all been supplied by Messrs. Platt Brothers and Co., Oldham.

The mill is driven by a pair of high-speed compound horizontal engines, capable of driving 2,000 I.H.P. The high-pressure cylinders are 27 inches diameter and low-pressure 46 inches diameter, all 5 feet 6 inches stroke, making 75 revolutions a minute. The fly-wheel is 22 feet diameter, grooved for forty cotton ropes of $1\frac{5}{8}$ inch diameter, giving a rope speed of 5,175 feet a minute; the driving is direct from the fly-wheel to the line shafts, which in the mule rooms make 300 revolutions a minute; the present indicated horse-power is 1,640. The whole of this work with pipe connections to the boilers was made by Messrs. Pollit and Wigzell, Sowerby Bridge. There are six boilers, 8 feet diameter and 30 feet long, with 110 lbs. working pressure, four of which are fitted with McPhail and Simpson's dry-steam generators. They are placed in a house alongside the engine house, with a Green's economiser behind containing 480 pipes; and were made by the Oldham Boiler Co.

OLDHAM CORPORATION ELECTRIC LIGHT WORKS.

These works, which were commenced in 1892, were completed and inaugurated on 15th March 1894. The streets provided with the electric light are the principal business streets in the town, and contain also the principal public buildings, the Town Hall, Art Gallery, Public Library, &c. Steam is provided by two steel Lancashire boilers, working at a pressure of 125 lbs. per square

inch. The furnace gases pass through an ordinary brick flue and through a Green's economiser to a chimney of ample dimensions. Coal can be brought into the station either from the Lancashire and Yorkshire Railway, which adjoins it, when the siding is constructed, or from the street. The engine room adjoins the boiler house. Four dynamos have been provided, each driven direct by a Willans engine, the total horse-power being 320. A switchboard stands at one end of the engine room, the space beside the engines being utilized for stores; and at the other end is an engineer's office with lavatories, &c. In the space below the office are placed a condenser and air-pump worked by a separate engine; and between the boiler house and the railway there is a reservoir for condensing water. The engines are so arranged that they can be worked either with or without condensation. Above the office is additional store accommodation; and above the engine room is a battery room, containing a battery of 59 cells of 500 ampère-hour capacity.

The station is so designed and constructed that the offices can be readily removed to its eastern end when extension becomes necessary or desirable. What is at present the eastern end of the building will then become its centre, the future eastern end being practically in elevation a duplicate of the present building. The present buildings however are sufficiently large for double the power now put down in them.

The plant is sufficient for the simultaneous lighting of about 2,500 incandescent lamps of eight candle-power each, ample reserve being provided in case of any machines requiring repair. Experience derived from the lighting of other towns shows that 2,500 lamps alight at one time correspond with a total of about 5,000 lamps actually erected. As the area to be supplied is small, and as there are many hours during which the amount of lighting required will be very small, a low-tension system of the simplest possible kind has been adopted: namely a two-wire system in which the current is distributed at 105 volts, but arranged throughout so that it is possible at any future time to change it into a three-wire system with a minimum of alteration, and without pulling up the footpaths or roadways.

The mains are bare copper carried upon stoneware insulators in concrete troughs or conduits under the footpaths. Where roadways are crossed, or where there is not room for a concrete conduit, the mains are laid as insulated cable, carried in cast-iron pipes or casings. The conduits are so arranged that fresh copper can be pulled into them without opening up the roads or footways beyond lifting the covers of the manholes.

Batteries are provided partly for a reserve, but mainly for the purpose of supplying current during the hours of minimum demand, which in Oldham is often a long period. They are charged by the dynamos during the hours when the latter have to work for supplying current to the circuit. By allowing them afterwards to discharge, the whole station can be shut down at night, and often in the morning also, so as to economise expenditure in wages and fuel. It has also been arranged that the waste gases from the corporation destructor on adjoining ground can be utilized under one of the two boilers, thereby saving a certain amount of fuel. The works were designed by Professor Alexander B. W. Kennedy, and have been carried out under his direction; they are now in charge of the resident engineer, Mr. S. Wilmott Newington. The architect of the buildings was Mr. C. Stanley Peach, London.

MESSRS. PLATT BROTHERS AND CO., HARTFORD IRON WORKS, OLDHAM.

This firm was founded in 1821 by Mr. Henry Platt, who previously had carried on a small business as a woollen carding-machine maker at Saddleworth. Prompted by a desire to extend his field of operation he removed to Oldham, and here began to make machinery for the manufacture of cotton. This enterprise succeeded so well that he deemed it necessary to introduce further capital into the business, which he did by entering into partnership with Mr. Elijah Hibbert, a prominent ironfounder in the town; and the firm then took the title of Messrs. Hibbert and Platt. Success attended their efforts to such an extent that in its subsequent

development the firm has now attained a magnitude far above that of any other textile machine works in the world.

The works are 55 acres in extent, exclusive of the collieries, and comprise the Old works, New works, Werneth spindle works, wood-sawing mill, forge and brick works, which are united by lines of railway connected with the Lancashire and Yorkshire Railway. Several locomotives are kept constantly at work during the whole day, conveying the trucks of raw material between the stations and the various parts of the works, and also taking out the trains of finished machinery.

The Old Works are situated about two miles from the New Works, and are quite independent in their working operations, having iron foundry, smiths' shops, special tool-making and millwrights' departments, turning, planing, fitting, and erecting rooms &c., where all the machines for ginning and for opening and carding cotton, wool, and worsted are made and packed for conveyance to the station.

The New Works are the largest of all, and have also their own steel, iron and brass foundries, smiths' shops, turning, planing, fitting, and erecting rooms, as well as special tool-making and millwrights' shops, where machines for combing, drawing, preparing, spinning both by mules and by ring frames, warping, sizing, and weaving cotton, woollen, worsted, and silk waste, are constructed, and delivered on trucks to the railway.

The Werneth Spindle Works are in close proximity to the New Works, and all the spindles and flyers for speed frames, as well as the spindles for ring-spinning frames, and for self-acting mules, twiners, and doubling frames, are made here, together with tin rollers and copper cylinders for the various machines. File-cutting is also an important branch of this establishment.

The saw mill and timber yard cover a space of eight acres. Here are numerous vertical and circular saws at work, reducing the largest logs of wood to planks of various widths and thicknesses. The machines, which are nearly all of the firm's own make, are driven by a compound horizontal steam-engine of 400 I.H.P. The timber yard is of great extent, and amply provided with lines of

rails and travelling-cranes for quick conveyance of the timber balks to the saws or elsewhere. In connection with the saw mill there are rooms in which all the operations of wood turning, planing, and joinering are carried on by means of the most improved appliances. There are also steam drying-stoves built on the fire-proof system, where the timber is dried before using; as well as large steers for seasoning the timber planks. The saw mill and timber yard are lighted by electricity by means of sixteen Brush electric lamps of 2,000 candle-power each. As much as 350,000 cubic feet of timber can be turned out of the saw mill in the course of twelve months. Adjoining the saw mill is the building devoted to the manufacture of the fluted iron rollers required in textile machinery. This building is in shed form, about 315 feet long by 100 feet wide, with a cellar under a portion of it. In the cellar the rollers are cut into the required lengths, and thence are taken into the shed above, where they are turned and fluted by means of lathes and fluting machines.

The stables, which are two storeys high, are close to the New Works, and built on the most improved plan. They have accommodation for 34 horses, and are independent of those at the Old Works and collieries. The new dining room, contiguous to the stables, is intended for the accommodation of the workmen and boys who live out of town; it is 200 feet long by 60 feet wide, and will seat comfortably 1,200 people; and it is amply provided with lavatories &c.

In the forge will be seen many furnaces, steam-hammers, and rolling mills at work, converting pig into wrought-iron for consumption in the various departments of the works; besides which a great quantity has also to be purchased.

In the brick works is fixed an automatic brick-making machine, capable of turning out about 34 bricks a minute, by what is known as the semi-dry process, which produces the smoothest and best surface bricks made by the trade (Proceedings 1859 page 42); the clay is passed through air-drying tubes, breakers, pulverisers, and disintegrators, from which it issues in fine dust; and is then pressed into semi-dried bricks ready for placing in the kilns, of which there

are six, each capable of holding about 70,000 bricks. Fire bricks are also made here from material procured from the firm's own mines.

The collieries have been acquired with a view to secure an ample supply of coal and coke of undoubted quality for the requirements of the works. The Moston colliery is situated about half way between Oldham and Manchester; the seams yield an excellent house-fire coal, as well as furnace coal. The Tunshill and Butterworth Hall collieries at Milnrow and the Jubilee colliery at Crompton, about four miles from Oldham, raise mountain mine coal of very pure quality; and here smithy coal, coke, and foundry coke are produced, containing a minimum of sulphur. The plant includes coal-washing apparatus, 108 coke ovens, and coal-crushing machinery making coal dust for foundry purposes. The Brushes Clough Sand and Fire-Clay Works, also situated in Crompton, supply the forge and foundries with sand of various kinds, especially ganister, which is obtained here of excellent quality. About 1,000 men in all are employed at the collieries; and the total number of hands employed by the firm exceeds 10,000.

PEEL COTTON SPINNING MILLS, BURY.

These mills are among the best examples of modern mills for spinning American cotton. The machinery, which is of the latest and most improved kind, was supplied by Messrs. Platt Brothers of Oldham, and the blowing rooms were fitted by Messrs. Lord Brothers of Todmorden. They have their own railway sidings, and are fire-proof throughout, fitted with automatic sprinklers, and lighted by electricity, which is generated by castle dynamos, made by Messrs. J. H. Holmes and Co. The dynamos are in a separate house, and are driven by two vertical compound high-speed non-condensing engines, each 90 horse-power, working at 200 lbs. pressure. In these engines slide-bars are dispensed with; the upper ends of the links coupling the pistons to the triangular connecting-rods are provided with ball joints, and these are adjustable from outside the

cylinders; they permit the pistons to revolve, so that all grooving of the cylinders, pistons, and trunks is avoided.

No. 2 Mill has a quadruple-expansion vertical engine, 1,600 horse-power, provided with Corliss valves throughout. The steam pressure is 200 lbs. per square inch, generated in four Lancashire boilers, 28 feet long and 8 feet diameter, made of steel and tested to 360 lbs. The cylinders are arranged in pairs on each side of the fly-wheel or rope-drum, the high-pressure and first intermediate cylinders on one side, and the second intermediate and low-pressure on the other. The cross-heads of each pair are connected by a pair of links and a triangular connecting-rod to a single crank; the two cranks of the engine are opposite to each other, so that the weights of the two sets of reciprocating parts are balanced. The action of the triangular connecting-rod is such that there is no dead centre. The cylinders are 18, 26, 37, and 54 inches diameter, with $4\frac{1}{2}$ feet stroke, and 80 revolutions a minute. There are two air-pumps, 26 inches diameter and 15 inches stroke. The rope drum is 21 feet diameter, with 36 grooves; the diameter of the ropes is $1\frac{5}{8}$ inch, and their velocity is 5,280 feet a minute or 60 miles an hour.

No. 1 Mill has a side-by-side compound engine of 1,300 horse-power, working at 95 lbs. pressure per square inch. The cylinders are 32 and 56 inches diameter by 6 feet stroke. The air-pump is 39 inches diameter by 31 inches stroke. The rope pulley is 32 feet diameter, and is grooved for 30 ropes of $1\frac{5}{8}$ inch diameter. The high-pressure cylinder is fitted with Corliss valves, and the low-pressure with slide-valves. Both engines were made by Messrs. John Musgrave and Sons of Bolton. The process of spinning yarn from the cotton as received in the bale to the finished cop will here be seen. The number of workpeople employed is 495.

On the occasion of the visit of the Members some particulars of the actual working of the mills were given by Mr. Henry Webb. The boiler house had originally been fitted up with what were believed to be the best mechanical appliances. Large cast-iron bins had been placed under the railway siding, so that the coal could be dropped into them from the wagons. Through small doors in the bottom of the bins the coal fell upon a wide belt, which conveyed it

to two boots in the boiler house; out of these it was lifted by elevators, and delivered into a long trough extending over the front ends of all the boilers. A creeper in the trough conveyed the coal along it into the hoppers placed over each fire-grate. Mechanical stokers were fitted to each boiler, and also movable fire-bars with a steam jet underneath to keep them cool. Mechanically these arrangements were perfect, altogether automatic, and it had been intended to convey the ashes back again to the wagons; and there was little or no smoke. But the whole plan was too costly, the wear and repairs were excessive, while little if anything was saved in attendance, and the coal consumption was too high. After a fair and exhaustive trial, all the mechanical appliances had now been taken away; and hand firing had been reverted to, with a large saving in the weight of coal used. With the quadruple-expansion engines the best week's work had been a consumption of 64½ tons of washed slack, costing 6*s.* 6*d.* per ton; the engines indicated 1,380 horse-power and drove No. 2 mill containing 100,000 spindles, half twist and half weft. The difficulties with the high-pressure steam had been in the main range of steam pipes, in which the flanges were too weak; but this had since been remedied. During the same week the side-by-side compound engine had used 64¼ tons of the same coal, and indicated 1,214 horse-power, driving No. 1 mill with 67,000 spindles, half twist and half weft. In both cases the coal used was all that came on the ground during that week, and included heating the mill both day and night. In cotton-spinning mills it is not usual to measure the quantity of water evaporated; what is wanted to be known by the owners is how much coal it takes to turn the spindles; in other words how much coal for the weight of yarn spun.

MESSRS. ADAM ASHWORTH AND SONS, AND MESSRS. LUCAS AND CO., FELT HAT MANUFACTORIES, BURY.

These works are engaged in the manufacture of wool felt hats. Up to twenty-five years ago all hats were made by hand, and no

change seems to have taken place in the manufacture previous to that date. All the special machinery now used is of American invention, if not of direct importation. The material used is called "noils," which is the fine short wool left after the longer fibre has been combed out. It is carded into a web, and wound on a revolving cone so constructed that the wool can be placed where it is wanted, making the hat thick or thin in the crown or brim as desired, varying from $1\frac{1}{2}$ oz. to $\frac{1}{2}$ lb. This is then put through various processes of felting, until it is a suitable firm or solid felt. The processes are called "planking," and the product a "body." It is then carbonized by acid and heat, to burn out all vegetable matter, &c.; and stiffened with gums, and dyed to the colour required. The next process is "blocking," in which after being softened by steam the body is pulled on to a block of approximately the required shape. The "finisher" puts it on a block of the exact shape and size desired, and shaves and treats it according to the finish required. The hat is next subjected to a pressure of 400 lbs. per square inch in a hot polished dish, which ensures the exact shape and size, adding also solidity and smartness. The final process of "trimming" is performed by girls. A collection will be seen of various styles of hats worn in different countries, which are more or less characteristic of the people wearing them.

MESSRS. THOMAS ROBINSON AND SON, RAILWAY WORKS, ROCHDALE.

These works are situated close to the Lancashire and Yorkshire Railway, and cover an area of about seven acres, Plate 104, employing about 1,200 men. Lying nearest to the railway are the saw mill and joinery works, where almost every kind of wood-work is produced direct from the log. The timber in the log is first sawn on a large horizontal double-saw frame, with two saws having a horizontal reciprocating motion; they are driven at a high speed from a double-throw crank, whose centres are opposite, so that the motion of the one saw balances that of the other. The saws cut in both

directions of their stroke, so that the feed of timber is continuous. Alongside is a vertical log-saw frame, arranged to work with a number of saws at once for sawing up small logs and deals. There are also various kinds of self-feeding circular saws; also planing machines, mortising and tenoning machines, &c. In addition to joinery, this department is largely devoted to the manufacture of flour-milling machinery, principally flour-dressing machines, such as semolina purifiers, sieves, bran dusters, &c., which follow the work of the roller mills in the conversion of grain into flour.

The machine works are separated from the wood department by a street, across which runs a branch line of rails connecting with the railway. Adjoining the street are the general offices, drawing offices, pattern shop, and foundries for iron and brass casting. Parallel to these buildings are large stores, the smithy, and the dressing shop for castings. Alongside the latter buildings runs a spacious yard, over the whole length of which works an overhead steam travelling-crane; here are stored the machine castings, previous to their entry into the fitting shops, which are on the other side of the yard. The works are so arranged that the raw material enters by the main line, and is discharged from the wagons direct at the foundry and smithy, from which during the course of manufacture it passes in direct circulation to the fitting shops and packing department. The iron foundry is a large building 317 feet long by 94 feet wide, built in two bays. A line of columns passes down the centre, supporting the roof and crane road. Three overhead steam travelling-cranes traverse the whole length of the building, each capable of lifting a load of ten tons. A number of machines are at work here for moulding pulleys and wheels and from plate patterns. The smithy is a similar building to the foundry, being lofty and spacious. It is 150 feet long by 45 feet wide, containing fifteen fires, and is fitted with steam-hammers, forging machines, and tools for special work in cutter making and stamping forgings. The lower end of the fitting shop is devoted to the construction of wood-working machinery, and the upper end to roller mills for flour milling and to steam engines. The total length of the fitting shop is 537 feet, and its width 103 feet. In addition to many special

turning, grooving, and milling machines, there is a balancing apparatus, by means of which pulleys and cutter-blocks are accurately balanced for the speed they are intended to run at. An overhead travelling-crane driven by rope works over the engine fitting shop, and is capable of lifting 15 tons. The machinery in this department is driven by a horizontal compound tandem engine of 40 horse-power, having an ordinary slide-valve with an arrangement whereby the cut-off is regulated by the governor according to the load.

NORTH END FINE-SPINNING COTTON MILL, BOLTON.

This mill containing 80,000 spindles was built and completed in 1890–91, and is an exceedingly good sample of a modern cotton-spinning mill suitable for producing Bolton counts. It is five storeys high, exclusive of basement, and is built of pressed brick, and fire-proof throughout, the floors being constructed of concrete and wrought-iron joists, laid on wrought-iron beams supported by cast-iron pillars. The whole of the joists and girders are of Belgian manufacture. One of the novel features in the construction of this mill is the position of the pillars, which are placed behind the mule creels, out of the way of the machinery and workpeople. The sanitary arrangements and ventilation have received special attention.

The engines, built by Messrs. J. and E. Wood of Bolton, are of the horizontal compound side-by-side kind, capable of working up to 1,200 I.H.P.; they are fitted with Corliss valves, and are supplied by four boilers of the ordinary Lancashire type, working at 100 lbs. pressure, and made by Messrs. Hick, Hargreaves and Co. of Bolton. The average amount of coal used for all purposes, including heating the mill, is under $2\frac{1}{2}$ lbs. per I.H.P. per hour. Power is transmitted from the rope pulley to the second motion or line shaft by means of ropes of $1\frac{3}{4}$ inch diameter.

The whole of the spinning machinery has been supplied by Messrs. Dobson and Barlow, and is specially adapted for making power-loom yarns of extra high quality. The machines in the card

room on the ground floor comprise those for cleaning and preparing the cotton for spinning in the rooms above. The first two processes in the card room consist of taking out the seed and short fibre, &c. The remaining processes in this room are for strengthening and arranging the fibre ready for the spinning mules. The quality of the article produced depends much on this department, and great care has been taken in the details and arrangement of the machinery. The four large spinning rooms are filled with self-acting mules of the latest design, and are constructed so as to obtain the maximum of production, while the quality of the material produced is not interfered with. The card room is lighted by the electric light on the inverted-arc system, and the basement and spinning rooms by the ordinary incandescent lamp. The mill is fitted throughout with Grinnell sprinklers, and with automatic fire-alarm; and stand-pipes and hose are placed in the staircase, which is outside the main building; thus all means possible are provided for preventing accident by fire.

MESSRS. DOBSON AND BARLOW, KAY STREET MACHINE WORKS, BOLTON.

These works are situated on the north side of the town of Bolton, in what was formerly known as Little Bolton. They date from the year 1830, and were used in succession to the old premises in Blackhorse Street, which had been occupied for the manufacture of spinning machinery from 1790. As a curious instance of how Lancashire towns have grown, it was considered, when the nucleus of the present establishment was built, that it was in an isolated neighbourhood, and much too large for any possible requirements. Since then the works have been increased tenfold, and are now in the midst of a dense population extending for miles around.

The works occupy over twelve acres, and although large additions have been made to the original buildings, by great care the modern requirements have been maintained; and, with the exception of the style of buildings, no disadvantage exists. In a preparing and

spinning-machine manufactory the variety of trades is enormous. Those under direct supervision in this establishment number no fewer than thirty-two.

The entrance gates in Kay Street open into a yard from which branch two main streets, one to the south and the other to the east, which lead to other streets and yards. The foundries are extensive; the heavy work is served by power cranes, the lighter by metal trams. There are five cupolas, capable of melting from 90 to 100 tons of castings per day. Two of the cupolas, on account of their proximity to the wood sheds, have the uptake turned over into a downtake, which is conveyed to the chimney by a flue, thus avoiding the dispersion of sparks in the air. The heated air, in passing, raises the temperature of the blast supplied to the cupolas, as the blast pipe passes through the hot-air flue. The cupolas are charged by power hoists. The chimney is 366½ feet high, and was for long the largest stack in the world; even now it has only two or three competitors. It was constructed for a chemical works formerly upon the ground, which has been absorbed by the machine works. There is a small steel foundry; also a brass foundry, and softening, annealing, and hardening furnaces.

The machinery made in this establishment is principally for cotton spinning and doubling, although silk, wool, and other fibres are also dealt with. Thus the machines may be divided into those for ginning, scutching, carding, combing, drawing and preparing, ring and mule spinning, ring and mule doubling, winding frames, gassing frames, and bundling presses; in fact all the requirements of a cotton mill. The fitting rooms are arranged to suit this category, and there is one general preparation in the way of planing, milling, polishing, and turning. Many of the milling and turning machines are made to serve a special purpose, and not a few of them show great ingenuity.

Bolt and nut turning, automatic screw-making, automatic wheel-cutting machines, multiple milling machines, are of various kinds and considerable in number. Subdivision of labour is the secret of the existence of the machine trade: without it competition with foreign makers would be impossible. Therefore it is that the machine-tools in the works have all been designed with a view to

economy of production. The work required is of the most exact character; in several cases pieces of 50 inches diameter of thin cast-iron have to be turned to the 1,000th part of an inch. The wood-working department is also extensive. Here again the object sought for has been to reduce the cost of labour. The multiplicity of pieces in a business of this description is almost incredible, the number of articles dealt with amounting to hundreds of thousands per week. The packing department for the large foreign trade is of great importance. Each framing and article of any weight is securely fastened by stays, which in turn are nailed to the case. About 1,000 cases of machinery per week are despatched to all parts of the world.

The boilers employed are of the Lancashire type, supplied with Galloway tubes, and furnished with mechanical stokers on the spreading system. Some of the engines are old; but there are three or four new ones, including two high-speed engines, one running at 240 revolutions per minute, and the other at 140. The bevel and spur wheels in connection with the driving gear have been abolished by degrees in favour of ropes or straps.

A large portion of the works is lighted by the inverted arc-lamp reflected from a white-washed ceiling (Proceedings 1893, page 396). In the dynamo room are different kinds of dynamo and switch arrangements. Electric welding is also a special feature in these works.

In the third storey of the building facing the principal entrance gates is an experimental room, where are samples, in working order, of the principal types of cotton-spinning machinery constructed. This room affords extremely interesting explanations of the principles of such machinery.

The offices are considerable in extent and organization. Their interest arises from the fact that the firm deals with cotton-spinning concerns in every quarter of the globe, and that it is necessary therefore to correspond in many different languages. The department for conducting the time and piece work and arranging the pay is an important feature. There are four pay offices, where 3,500 men and boys are paid in twenty minutes each week, the pay proceeding simultaneously in each office.

MESSRS. HICK, HARGREAVES AND CO., SOHO IRON WORKS, AND PHŒNIX BOILER WORKS, BOLTON.

The Soho Works were erected in 1832 as a general engineering establishment, the earlier products being stationary steam-engines, boilers, mill-gearing, hydraulic machinery, water wheels, marine engines, and locomotives; of the last a large number were made here for the Liverpool and Manchester and other early railways.

The firm were the first to introduce the Corliss engine into this country about 1865 (Proceedings 1868, page 181), and they have been closely identified with it ever since. Over 1,100 of these engines have been built of all sizes from 40 to 10,000 I.H.P., simple, compound, and triple-expansion, adapted for all pressures up to 200 lbs. per square inch. Great attention has been given to obtain the best results, as regards economy of fuel and water, and regularity of speed under varying loads; the consumption of water or steam is now under 12 lbs. per I.H.P. per hour, and the fuel $1\frac{1}{4}$ lb. per I.H.P. per hour under favourable conditions, whilst the variation in speed is practically so insignificant that it may be neglected.

Steel boilers were first made at the Soho Works in 1863; and their present capacity, including the Phœnix Works, is about 150 boilers a year. The boilers are mostly of the Lancashire type, but upwards of 200 torpedo-boat boilers of the locomotive type have been made; some of the most recent of these have each 2,400 square feet of heating surface, and whilst weighing only 16 tons have given 1,750 I.H.P. on the trial trip. Mill gearing in all its branches is also a speciality; some large fly-wheels for rope-driving have been made, a recent example being 32 feet diameter, grooved for 56 ropes, weighing 128 tons, and to transmit 3,000 I.H.P. Turbines and hydraulic machinery are also largely manufactured.

The works have been extended from time to time to suit the growing requirements of the business, and they now cover seven acres, and give employment to about 1,000 workmen. They are divided into nine departments: namely two pattern shops, brass foundry, three moulding shops, smiths' shop, heavy machine shop, light

machine shop, with fitting and erecting shop, millwrights' turning shop, and millwrights' erecting shop. The tools are modern, many being of a special character to suit the work. There are ten rope-power travelling-cranes from 15 to 40 tons capacity. Some of the leading tools are of large size: namely a lathe 4 feet 6 inches centres, 14-inch spindle, and bed 50 feet long; a side planer to plane 24 feet long by 12 feet high; a slotting machine with a stroke of 4 feet 6 inches; a pit planer to plane an object 20 feet long by 10 feet square; a tool for turning rope fly-wheels, capable of dealing simultaneously with four fly-wheels, each 32 feet diameter by 40 ropes, as many as thirty cutting tools being sometimes in use simultaneously on one wheel; and an 80-ton hydraulic riveter with 8 feet gap. The motive power consists of five Lancashire boilers 7 feet diameter by 30 feet long, working at a pressure of 70 lbs. per square inch; and six engines, giving altogether about 450 I.H.P. The works are advantageously situated, being traversed by sidings from the London and North Western Railway.

The Phœnix Boiler Works were purchased in 1891, the boiler department at the Soho Works having become inadequate to meet the demands upon it. It is contemplated to remove all the boiler-making plant to these works, and to utilize for other purposes the space now occupied by the old boiler shop at the Soho Works.

MESSRS. JOHN MUSGRAVE AND SONS, GLOBE IRON WORKS, BOLTON.

This firm of engineers, boiler makers, and millwrights, was established in 1839 by John Musgrave, and has been worked and carried on by his sons and grandsons up to the present time. At first the works employed only about fifteen men; but the growth of the business has necessitated continual alterations and additions, until the works now occupy over eight acres, almost entirely covered by buildings, including three foundries, with complete accessories of pattern shops, dressing shed, store rooms, &c. There are four shops devoted to engine work, and four others for millgearing, besides

large engine-erecting shops, and extensive boiler works, smiths' shop, and all the numerous adjuncts, providing employment for about 1,000 men. The special work produced comprises quadruple, triple, and compound engines, with triangular connecting-rods, and having no dead centres; also quick-speed engines on this principle, designed specially for electric machinery; Musgrave's barring engine and Corliss valve-gear, Crompton's metallic packings for piston-rod glands, Buckley's piston-rod support, Tabor indicator, &c. The engines are constructed with a special view to high-class finish, steady turning, and economical running; they are driving a large number of the most successful cotton-spinning and weaving mills in this country, India, Russia, Germany, and Japan; and examples of the work here produced have gone into nearly every part of the world.

LANCASHIRE AND YORKSHIRE RAILWAY LOCOMOTIVE WORKS, HORWICH.

These works, of which the building was commenced in 1886, have been erected for the purpose of repairing and renewing the locomotive stock, and of carrying out the mechanical engineering work of the railway. They are situated between the Chorley New Road, Horwich, and Red Moss; and are about one mile distant in an easterly direction from Blackrod Station upon the main line between Manchester and Fleetwood. The land enclosed for the works comprises 85 acres, and lies north-west and south-east, Plate 105. The covered area of workshops is 15 acres. They comprise offices, general stores with gallery, boiler shops, smithy, forge, foundries, tin and copper shops, machine shops, erecting and repairing shops, &c.

The general stores contain light goods on the upper floor, and heavy material on the ground floor. The boiler shop is fitted with the necessary cranes, portable and fixed riveting machines, multiple drilling machines, pneumatic fullering tools, quadruple stay-tapping, and plate-edge planing machines. The boiler shop and smithy

contain a hydraulic flanging press; and in the forge are a plate-straightening machine, rolling, tire, and merchant-mill engines, tire and merchant mills, and 30-ton duplex hammer. In the steel foundry are smelters, core-drying furnaces, and a wagon-wheel moulding-machine, &c.; and the iron foundry is adapted for light and heavy castings. The steel dressing shop contains annealing furnaces, and is used for dressing steel castings. The wagon-wheel shop comprises lathes for boring and turning wagon-wheels; one set of lathes rough the work, and the remainder finish it. Bolt machines, drop stamps, and nail-making machines are in the bolt shop of the smithy. The smithy is fitted with smiths' hearths, frame fires, and Roots' blower, &c.; whilst in the spring smithy are furnaces, spring thinning, punching, and shearing machines, and a hydraulic buckle-press, &c. The signal shop is used for the fitting up of locking frames and general signal work. The points and crossings shop contains machines for planing rails, points and crossings, &c. The fitting and machine shop comprises milling and other special tools adapted to the work required. For the conveyance of the material to the various machines, these shops are fitted with walking cranes to lift weights up to 5 tons. The brass moulding shop contains gas furnaces, core stoves, &c.; and in the tinsmiths' shop are machines and tools for general work. The coppersmiths' shop is set apart for copper-pipe work, the making of dome covers &c., and contains brazing furnaces and copper-pipe bending press. In the telegraph shop are screw-making and other light machinery, and fittings for the electrical instruments required for the railway. The joiners' and pattern-makers' shop is fitted with modern wood-working machinery.

The erecting and repairing shop is provided with 30-ton cranes, portable hydraulic riveters, flexible-shaft drilling-machine, and the necessary complement of tools. Steel castings are largely used in the manufacture of the locomotives. The tender shop is for the making and fitting up of tenders; and the paint shop contains the necessary paint-grinding and mixing machinery and stores. In the chain-making and testing shop is a 100-ton chain-testing machine, together with the necessary chain-makers' fires, &c.

To facilitate the carriage of material from the stores, and of work to the various shops, a system of 18-inch gauge tramway is laid to the extent of $7\frac{1}{4}$ miles, the haulage being performed by small locomotives. The shops and offices are fitted with both arc and incandescent electric lights. The fitting shop is lighted with inverted arc lamps; and each department of the works is also in telephonic communication with the offices.

LONDON AND NORTH WESTERN RAILWAY, STEEL AND LOCOMOTIVE WORKS, CREWE.

The chief objects of interest in the several departments of the works are as follows, Plates 106 and 107. Bessemer converting house. Siemens-Martin furnace house. Rail mill; rolling of 60-foot rails. Point and crossing shop; group of special machines for manufacture of points and crossings. Boiler shop; hydraulic riveting machines, boiler-stay tapping machine, electrical cranes and drills, pneumatic caulking machine, &c. Flanging shop; hydraulic presses punching and flanging boiler-plates. Boiler mounting shop; electrical tube-cutter, &c. Iron foundry. Tender shop; hydraulic riveting, and building of tenders and carriage frames. Repairing shops; horn-block planing-machine, valve-facing and cylinder-boring machines, &c. Forge and rolling mills; plate-mill for rolling boiler-plates; 7-foot saw cutting steel casting gates cold; 8-ton hammer working on crank-shafts; 30-ton hammer slabbing boiler-plates; carriage-tyre rolling; fish-plate rolling, punching, and straightening; and merchant and guide mill. Steel foundry. Bolt and nut shop; special group of machinery for forging and finishing nails, rivets, bolts, and nuts. Wheel shop; group of machines for finishing wheels and axles, electrical cranes, &c. Signal shop; electrical staff instruments. Paint shop. Testing shop; machines for testing tensile strength of plates; hydraulic bending and drifting machine; chain, cement, and oil-testing machines. Millwrights' shop. Joiners' shop and saw-mill; special wood-working machinery.

Old Works.—Smiths' forge, smithy, and spring shop; electric welding machine. Locomotive erecting, wheel, and fitting shops.

Compound and Non-Compound Locomotives.—In order to test the capabilities and determine the relative advantages and suitability of Compound and Non-Compound Locomotives for working mineral and ordinary goods traffic, trials were made on 1st April 1894 with two trains running between Crewe and Stafford, worked by 4 ft. 3 ins. eight-wheeled coupled coal engines, one compound No. 50 and the other non-compound No. 2524, recently built at the locomotive works of the London and North Western Railway from the designs of Mr. F. W. Webb, Chief Mechanical Engineer.

The two trains were composed of loaded coal wagons and the necessary brake vans, which were all carefully weighed previous to the trials. No. 1 train consisted of one dynamometer car, fifty-two loaded wagons and three brake vans; total weight of train 695·68 tons, exclusive of engine and tender. No. 2 train was made up in the same way, except that in place of the dynamometer car a loaded wagon was substituted, equal in weight to the car; total weight of train 690·82 tons, exclusive of engine and tender.

In carrying out the trials, both trains were marshalled side by side on the main line opposite to the south junction signal box at Crewe. The engines were then attached, the compound to No. 1 train with the dynamometer car and the non-compound to No. 2 train. Each engine had the same amount of fire in the box, the same height of water in the boiler, and steam up to full working pressure. Both trains were started, and ran side by side to Stafford, instructions having been given to the drivers to keep the engines level with each other. On arriving at Stafford the engines were turned and re-attached to their respective trains, which they worked back to Crewe, side by side as before. The engines were then changed from one train to the other, and two more trips run to Stafford and back in exactly the same way as the two previous trips: so that all the conditions of working were the same for both engines. The coal used, which was South Wales, was carefully weighed, that for lighting up and raising steam being kept separate from that used during the trips, which latter for convenience was put into bags weighing 84 lbs. each.

Compound and Non-Compound Locomotives.

Results of Trials.

1 April 1894.	Engine No. 2524. Non-compound.	Engine No 50. Compound.	Saving by Compound Engine.
Mean weight of train — including engine and tender . . .	768·85 tons	767·565 tons	
Mean weight of train — excluding engine and tender . . .	693·25 tons	691·715 tons	
Ratio of weight of engine and tender to weight of train . . .	1 to 9·17	1 to 9·12	
Number of axles in train, including engine and tender . . .	120		
Mean speed, miles per hour . .	17·74 miles		
Maximum speed, miles per hour .	34 miles		
Total length of four trips . .	96 miles		
Coal for lighting up and raising steam	1,039 lbs.	1,039 lbs.	Per cent.
Coal consumed on trips . . .	5,824 lbs.	4,462 lbs.	23·38
Total Coal consumed, including steam raising	6,863 lbs.	5,501 lbs.	19·84
Coal consumed per mile — excluding steam raising .	60·66 lbs.	46·48 lbs.	23·38
Coal consumed per mile — including steam raising .	71·49 lbs.	57·30 lbs.	19·84
Total Water evaporated . . .	54,520 lbs.	41,125 lbs.	24·5
Water evaporated per pound of coal — excluding steam raising .	9·36 lbs.	9·21 lbs.	
Water evaporated per pound of coal — including steam raising .	7·94 lbs.	7·47 lbs.	
Total Ton-Miles — including weight of engine and tender . . .	73,809·6	73,686·24	
Total Ton-Miles — excluding weight of engine and tender . . .	66,552·0	66,404·64	
Coal consumed per mile per ton of train — Including weight of engine and tender, and			Per cent.
excluding steam raising	1·262 oz.	0·969 oz.	23·2
including steam raising	1·487 oz.	1·194 oz.	19·7
Excluding weight of engine and tender, and			
excluding steam raising	1·400 oz.	1·075 oz.	23·2
including steam raising	1·650 oz.	1·325 oz.	19·7
Maximum pull on drawbar . . — at starting .	10·75 tons	11·5 tons	
Maximum pull on drawbar . . — while running	7·25 tons	6·6 tons	
Highest indicated horse-power developed	608·6 I.H.P.	656 I.H.P.	

Every care was taken to ensure the perfect accuracy of all the particulars taken during each trip, an assistant being stationed on each engine to take the steam pressures, measure the quantity of water used, and note the number of bags of coal used. Indicator diagrams were taken simultaneously on each engine at intervals in going up the banks on all the trips; and the pull on the engine drawbar and the speeds were accurately registered in the dynamometer car. The steepest gradient was 1 in 177. At the end of the trials a small fire only was in each of the fire-boxes, and the water level in the boilers was the same as at the start.

In page 460 is given a detail statement showing speeds, coal consumption, weight of trains, &c. The slight difference in the mean weight of the two trains is due to several wagons in No. 1 train having to be removed at the end of the second trip (Stafford to Crewe), owing to hot axles; and fresh wagons were put in their places, which on being weighed afterwards were found to be rather lighter than those removed.

LANCASHIRE WATCH WORKS, PRESCOT.

The industry of watchmaking was first introduced into England during the Commonwealth, nearly two hundred and fifty years ago; and the trade seems soon afterwards to have been established in Prescot, and to have progressed concurrently with the development of the watch itself. All the other centres of watchmaking in England, including London, Coventry, Birmingham, and Liverpool, have been dependent on Prescot makers for the foundation of the watch, called the movement, which consists of the frames, barrels, fusees, detent works, indexes, silver pieces, wheels, pinions, ratchets, springs, &c. Besides the movements, other branches of watchmaking were carried on in Prescot, such as the manufacture of balances, hands, rollers, levers, pallets and wheels, verges and motions. Ships' chronometer movements have likewise been manufactured here; and watch-tool making had its seat in the locality.

The buildings of the Lancashire Watch Co., which was established in 1889, occupy a rectangular plot of ground of about eleven and a half acres. When completed the front building will be 440 feet long by 28 feet wide and four storeys high, the central portion forming the administrative department. Behind the whole length of this building, and separated from it by areas for light, will be the main works corridor, 20 feet wide, from which the different workshops will be entered. The latter will be placed with their length at right angles to the corridor, and are intended to be seven in number; the outer will be three storeys in height, and the inner one storey. The rear of all the workshops is intended to be connected together by a rope-race for the transmission of power by cotton ropes, the areas between the workshops being approached through archways. The steam engines, boilers, and electric-lighting plant are intended to be in the centre of this rope-race.

The buildings already completed consist of one of the three-storey outer workshops and two of the one-storey inner shops, occupying a space of 300 feet by 260 feet, and having a total floor area of 59,325 square feet. The three-storey workshop is 300 feet long by 28 feet wide. The large one-storey workshop is 336 feet long by 100 feet wide, a portion at one end being temporarily divided off for the present engine and boiler and other purposes. The smaller one-storey workshop is 256 feet long and 45 feet wide. The present offices are contained in what will ultimately be the main works corridor.

The sidewalls of all the workshops are constructed of cast-iron stanchions, filled in to a height of three feet above each floor with brickwork, and over this with glass in wood frames, so that continuous windows are formed the whole length of each side. The ground floors are solid, formed with a layer of ballasting and a layer of Portland cement concrete. The upper floors are fire-proof, with steel girders supported on cast-iron columns. The three-storey workshop has an ordinary slated roof, but the one-storey workshops have saw-tooth shed roofs, with large skylights facing the north. Blackman air-propellers are used for ventilation; and the outlet ventilators are of the induced-current kind, preventing down-draft.

The buildings are heated throughout by steam generated in a boiler 30 feet by 8 feet.

The motive power is provided by a locomotive-type boiler, working at 140 lbs. pressure, and supplying steam to a Marshall compound engine capable of developing 80 horse-power, from which the various shafts are driven by cotton ropes working in iron grooved pulleys. The shafting is of steel throughout, and the belt pulleys being made in halves will fit on it anywhere.

The work benches have wood tops $2\frac{1}{2}$ feet wide, carried on cast-iron standards, which are secured to the floor-boards and joists. The total area of bench tops is 14,480 square feet. Gas is used at present for lighting.

The smaller one-storey workshop is used for making tools, and has joiners' shop and smithy partitioned off at one end; it provides accommodation for about 100 mechanics. The larger one-storey workshop is employed in the making of watch movements, with accommodation for about 600 workpeople. The first floor of the three-storey workshop contains the flat-steel and stem-winding departments; the second floor is used for jewelling, gilding, and escapement and balance making; and the third floor for assembling-room, and dial and hand making. These three storeys give space for the employment of 700 workpeople. The press room is on the ground floor. The factory as it at present stands provides accommodation for at least 1,500 workpeople, and turns out now a minimum of 500 complete watches a day.

MEMOIRS.

JAMES CROSS was born at Uddingston, near Glasgow, on 22nd February 1829. He was a civil engineer by profession, and in 1853 became managing engineer of the old St. Helen's Railway and Canal Co. In 1864 however the railway and canal were sold to the London and North Western Railway, and his connection with the undertaking then ceased. He was also owner of a locomotive works at St. Helen's Junction. In March 1865, on the death of Mr. John Hutchinson, one of the founders of Widnes, he became one of the three trustees of the estate, which consisted of chemical works, land, and the West Bank Dock. Shortly afterwards he gave up his works at St. Helen's Junction, and became managing trustee and personal superintendent of the estate. He took an active part in public affairs at Widnes, being a member of the local board for many years, and chairman from 1875 to 1882. He was also chairman of the highway committee, and as an engineer took a great interest in drainage matters, and in the gas and water undertakings of the board. He was chairman of the Upper Mersey Conservancy. He constructed the railway from Widnes to Hough Green for the Sheffield and Midland Companies. Having been a major of the 47th Lancashire Rifle Volunteers, he was permitted to retain this rank on his retirement from the corps; and received the Queen's decoration for long service. He was also a justice of the peace for Denbighshire, residing latterly in North Wales, at Mold and afterwards at Llangollen, where his death took place on 15th October 1894, at the age of sixty-five. He became a Member of this Institution in 1865.

ANTONIO GOMES DE MATTOS was born at Rio de Janeiro on 3rd December 1829. After being educated at the Naval College of Rio, where he matriculated, he entered the Brazilian navy as

midshipman and saw some service, taking part in the expedition and naval engagement of Tonelero; and he attained the rank of first lieutenant. In 1852 he was one of the officers selected by the Brazilian government to study mechanical engineering and naval construction in England, and was articled to Messrs. John Penn and Sons, Greenwich. After serving his time he returned in 1857 to Brazil, and was appointed directing engineer of the marine arsenal at Rio. His first care was to re-organise the workshops, and to refit them with modern tools and appliances; after which he commenced the construction of marine engines and other work required for the naval service, and carried out many improvements in the dockyard. In 1864 he retired from the government service to join the firm of Messrs. John Maylor and Co., engineers and naval constructors at Rio, and soon undertook the entire management of the works; in 1879 he became the sole proprietor under the title of Messrs. A. G. de Mattos and Co. During the Paraguayan war he rendered important services to the government by the prompt repairs of war ships and by placing the resources of the factory at the disposal of the government for the casting of shell, shot, and other munitions of war; these services were duly recognised. In 1890 his establishment was purchased by the Lloyd Brazileiro Co., proprietors of the mail lines of steamships and docks at Rio; for whom he became managing director of the dry docks and engineering shops for three years, until his final retirement in 1893. During his career he undertook many important contracts for the Brazilian government, including the erection of a system of hydraulic cranes and lifts in the docks and custom house at Rio; and was actively engaged in the construction of land and marine engines, in the repairing of steam ships for Brazilian and other navigation companies, and in the manufacture of machinery for sugar and coffee estates in the interior. He was the author of a work on the culture of sugar cane and manufacture of sugar. In recognition of services to his own and other governments he was created a commander of the Brazilian Order of the Rose, a chevalier of the Legion of Honour of France, and a chevalier of the Order of the Crown of Italy. His death took place suddenly at his residence in

Tijuca, near Rio, from failure of the heart, on 13th May 1894, in his sixty-fifth year. He became a Member of this Institution in 1875.

THOMAS ALBERT OAKES TAYLOR was born in Leeds on 13th September 1849, being the only son of George Taylor, who was the founder of the Clarence Iron and Steel Works, Leeds (Proceedings 1876, page 24). About 1872 he became managing partner in these works, and since his father's death in June 1875 was the senior partner. He died on 22nd August 1894, from congestion of the lungs, in the forty-fifth year of his age. He became a Member of this Institution in 1882.

JAMES BRADFORD TREW was born at Swansea on 18th July 1859, and was educated at Queen's College, Taunton. He served his time with Messrs. Vivian and Son in their constructive works at Swansea, and completed his course in the drawing office and works of Messrs. Muir and Houston, marine engineers, Glasgow. He next assisted Mr. James W. Chenhalls in the construction and erection of machinery for a chemical works at Morriston, near Swansea. Afterwards he went to sea, and served in several large steamers trading with the East under the superintendence of Messrs. Flannery and Baggallay, and others. Having passed the Board of Trade examinations, including that of extra chief engineer, he went to Japan in 1887, and served in the Nippon Yusen Kaisha. On his return to England in 1893 he superintended the finishing and took charge of some new engines for an engineering firm at West Hartlepool in a large steamer engaged in the China trade, and while on this duty was attacked with fever at Hong Kong, and died there on 18th September 1894, at the age of thirty-five. During his career he made a special study of electric lighting on board ship, and superintended several installations on ships he had to do with. He became a Member of this Institution in 1886.

HENRY YATES was born at Walton-le-Dale, near Preston, on 28th October 1820. After being educated at a private school near

Liverpool, he was apprenticed to Messrs. Nasmyth and Gaskell, Bridgewater Foundry, Patricroft. On the termination of his apprenticeship he was sent by Mr. Nasmyth to France, to assist in the construction of the first railway there from Paris to Rouen. In 1846 he returned to England, and was employed in the locomotive works of the London and South Western Railway to superintend the construction of their new engines and rolling stock. There he remained until 1853, when he was engaged by Mr. C. J. Brydges, managing director of the Great Western Railway of Canada, to go out for a term of years as chief locomotive superintendent and mechanical engineer of the whole line. In 1857 he entered into an arrangement with Captain Barlow to complete the Buffalo and Lake Huron Railway, receiving the position of chief mechanical superintendent and engineer. In 1862 he became chief contractor for the maintenance of the permanent way and the whole of the works between Buffalo and Goderich. In 1863, on Sir Edward Watkin becoming president of the Grand Trunk Railway, he was appointed chief engineer of the whole railway and its branches, which position he held until 1866. He was afterwards engaged more or less as engineer and contractor for works in connection with the same railway from 1880 to 1886. The Michigan Air Line Railway was surveyed, plotted, and completed under his entire supervision as chief engineer. Since then he was engaged as consulting engineer in various railway matters in Canada. During his active career of thirty-five years he introduced several important improvements in locomotives. In 1869 he entered into partnership with Mr. John H. Stratford for supplying railway materials. He was an alderman and also a justice of the peace of the city of Brantford, Ontario. His death took place at his residence at Brantford from Bright's disease, on 22nd July 1894, in his seventy-fourth year. He became a Member of this Institution in 1878; and was also a Member of the Canadian Society of Civil Engineers.

Institution of Mechanical Engineers.

PROCEEDINGS.

October 1894.

The Autumn Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Wednesday, 24th October 1894, at Half-past Seven o'clock p.m.; Professor Alexander B. W. Kennedy, LL.D., F.R.S., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following forty-five candidates were found to be duly elected:—

MEMBERS.

Bennett, James William,	Batavia.
Burke, Michael James,	Morvi.
Chaffey, George,	London.
Craven, William H. S.,	Manchester.
Gatehouse, Tom Ernest,	London.
Hamer, Walter,	Bolton.
Herman, Benjamin Richard,	Karachi.
Iorns, Charles Risbec,	Manchester.
Jenkin, Thomas Henry,	Hull.
Lloyd, Sampson Zachary,	Birmingham.
Longridge, Capt. Cecil Clement,	Birmingham.
McQueen, John,	Manchester.
Merrick, Robert,	Cork.
Pickering, Jonathan,	Sydney.

Pryce, Henry James,	London.
Smith, William,	Sydney.
West, James,	Orange Free State.
West, John,	Manchester.

ASSOCIATE MEMBERS.

Armstrong, William Henry,	Calcutta.
Aveline, William Rebotier,	Bombay.
Clark, James Lester,	London.
Collis, Alfred Edward,	Lincoln.
Coventry, Theodore,	Manchester.
Dadina, Hormuz Minocher,	Bombay.
Dickinson, Harold,	Leeds.
Eastmead, Frederic James,	London.
Ewen, John Taylor,	London.
Finlayson, David,	Glasgow.
Hall, Robert Frederick,	Birmingham.
Hardy, William,	Bessbrook.
Harris, Herbert Nelson,	Bridport.
Henderson, Arthur James,	London.
Mansfield, Edwin Albert,	London.
Mills, Arthur Edwin,	Bath.
North, Horace,	Brighton.
Ramsbottom, John Goodfellow,	Manchester.
Salis, Henry Rodolph de,	Oxford.
Smith, William Arthur,	Northampton.
Thomson, Henry,	Cawnpore.
Wasdell, Thomas, Jun.,	Birmingham.
Young, Smelter Joseph,	Bolton.

ASSOCIATE.

Cowles, William S., Lt.-Com. U.S.N.,	London.

GRADUATES.

Britten, Thomas,	Lincoln.
Jamieson, James Lindsay Auldjo-,	Newcastle-on-Tyne.
Lloyd, Thomas Zachary,	Birmingham.

The President announced that, in accordance with the Rules of the Institution, the President, two Vice-Presidents, and six Members of Council, would retire at the ensuing Annual General Meeting; and the list of those retiring was as follows:—

PRESIDENT.

Alexander B. W. Kennedy, LL.D., F.R.S., London.

VICE-PRESIDENTS.

Sir James N. Douglass, F.R.S., . .	London.
Edward B. Marten, ...	Stourbridge.

MEMBERS OF COUNCIL.

John A. F. Aspinall, ...	Horwich.
William Dean, ...	Swindon.
Benjamin A. Dobson, ...	Bolton.
Francis C. Marshall, ...	Newcastle-on-Tyne.
Henry D. Marshall, ...	Gainsborough.
J. Hartley Wicksteed, . . .	Leeds.

All of these offered themselves for re-election, with the exception of Sir James N. Douglass and Mr. Marten.

The following nominations had also been made by the Council for the election at the Annual General Meeting:—

Election as Member.	VICE-PRESIDENTS.	
1861.	Samuel W. Johnson, . . .	Derby.
1868.	J. Hartley Wicksteed, . .	Leeds.
	MEMBERS OF COUNCIL.	
1873.	Henry Davey, ...	London.
1873.	Bryan Donkin, . . .	London.
1885.	Thomas Mudd, ...	West Hartlepool.
1891.	Ralph H. Tweddell, . .	London.
1891.	Arthur T. Walker, . . .	Leeds.

The President reminded the Meeting that according to the Rules of the Institution any Member or Associate Member was now entitled to add to the list of candidates.

No other names being added, the President announced that the foregoing names would constitute the nomination list for the election of officers at the Annual General Meeting.

The following Paper was then read and discussed:—

"The Manufacture of Standard Screws for Machine-made Watches;" by Mr. Charles J. Hewitt, of Prescot.

Shortly after Nine o'clock the Meeting was adjourned to the following evening. The attendance was 79 Members and 45 Visitors.

The Adjourned Meeting was held at the Institution of Civil Engineers, London, on Thursday, 25th October 1894, at Half-past Seven o'clock p.m.; Professor Alexander B. W. Kennedy, LL.D., F.R.S., President, in the chair.

The following Paper was read and discussed:—

"Drilling Machines for Cylindrical Boiler Shells;" by Mr. Samuel Dixon, of Manchester.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers, for their kindness in granting the use of their rooms for the Meeting of this Institution; and particularly on the present occasion for the special arrangements made for the comfort and convenience of the Members attending during the reconstruction of the building.

The Meeting then terminated shortly after Nine o'clock. The attendance was 81 Members and 47 Visitors.

THE MANUFACTURE OF STANDARD SCREWS FOR MACHINE-MADE WATCHES.

By Mr. CHARLES J. HEWITT, of Prescot.

In the whole range of mechanics as applied to the particular industry of Watch-making there is probably no subject of more general interest to mechanical engineers than that of the apparently trivial Screw. In addition to its general interest, there is no subject of greater mechanical importance in this industry, as economy in production has gradually made more and more demands upon the machine-designer and toolmaker; and the number of screws used in each watch, when multiplied by the total product of a watch factory, has justified expensive and elaborate machinery for their manufacture.

Defective Screws.—The fit and finish of the screw-heads make or mar the appearance of the watch; and the fit and shape of the thread have such an effect on its durability, that many watches, otherwise of good quality, come to an untimely end through failure of the screws to perform their allotted task. There are few watch-repairers who have not experienced the sudden transition from satisfaction at the successful termination of a conscientious piece of work, to disgust upon finding the balance-bridge screw over-turn, in consequence of which the work thought to be complete has to be gone through once more. If the repairer happens to be impatient or unscrupulous, he treats the unfortunate watch with a roughness varying only in degree of barbarity. Instead of taking the watch to pieces again, re-tapping the hole, and fitting a new screw, he tries to find one that will do; but the quest is not easy, considering that until recently no recognised standard for threads existed. The natural result is a botched job; and each successive watch-repairer

treats it as derelict, and it quickly finds its way to an unhonoured scrap-heap. In the watch trade it is customary to lay the blame on the repairer, when a case such as this occurs; but the source of trouble ought to be sought much further afield. The recent advances effected in machinery for watch-making have rendered it quite practicable to make watches with screws that will not over-turn with any reasonable usage.

Principal Defects.—The defects principally met with in hand-made screws were drunken and cross-winding threads, and variable diameters. To these should be added the irregularities which hand work necessarily entails. These defects came mostly from the absence of good mechanical methods for originating and maintaining the standards. In the ordinary practice of watch-making by hand methods, it was usual in commencing screw-making to buy a screw-plate, from which taps were made; these taps were then used to make the actual working screw-plates, and the latter generally contained thirty or forty holes. Out of these holes those were chosen which produced screws most pleasing to the eye. Other master-taps were often taken from these working plates, and used for making other working plates: no thought being given to the fact that these successive stages evolved a standard quite different in size and pitch from that started with. It will readily be seen that the only way by which even a moderate degree of accuracy could be obtained was by fitting each series of screws into holes in which they finally remained, all interchange being prohibited. Under the system of watch-making then in vogue, the result was not so disastrous as may now appear, because the movement-maker fitted the screws in the rough, and no large stocks of screws and movements were necessary: thus an account could be kept of each series of screws, and they could be fitted according to the necessities of the case. These screws were hardened and polished separately by the finisher, who put them back into their respective places: so that no great difficulty arose through want of interchangeability, until the watch got into the repairer's hands. Moreover the change from the standard screw was so gradual that it could not be detected by the

means of measurement then used; nor had the variation become so great as to cause practical inconvenience enough to condemn the plan.

Factory system for Screws.—With the advent of the factory system however, the old methods became impossible. The finished screws could not be fitted to the watch in the early stages of manufacture, because the later operations would spoil the polish; nor could they be economically fitted in the rough and be afterwards polished by the finisher, because the essence of the factory system is economy of skilled labour. Large stocks of material in each department are also necessary in the factory system, because a slight derangement of one department brings the whole organisation to a stand-still unless there be sufficient stock to fall back upon. Thus screws made today may be fitted into holes tapped months previously or months later. To meet all these contingencies, nothing would suffice except so making and finishing the screws that any screw should go into any watch after gilding, without any previous fitting. In effecting this change, the adoption of a standard thread had first to be considered; and secondly, methods had to be evolved for retaining this standard, so that watches made today might if necessary be supplied with new screws made twenty years hence.

Standard Screws.—The standard recommended by the committee of the British Association * appointed for the purpose is the one adopted by the Lancashire Watch Co., Prescot, with which the writer is connected; and all information with respect to the standard may be obtained from Professor M. Thury's "Systématique des Vis Horlogères." It is a V thread of $47\frac{1}{2}°$, rounded top and bottom with a radius equal to 2-11ths of the pitch, Fig. 16, Plate 116; and the pitch P is directly related to the diameter D by the formula $D = 6\,P^{\frac{6}{5}}$. This formula will of course give an unlimited number of sizes; and in order to formulate a standard series it was decided to adopt the successive powers of 0·9 mm. for the

* Report 1882, pages 311–14; and 1884, pages 287–93.

pitch. The index of the power is used as a convenient designating number for the screws: thus the pitch of No. 6 screw is got by raising 0·9 mm. to the sixth power, the pitch being therefore 0·53 mm. and the diameter 2·8 mm. From the figures so obtained in decimals of a millimetre a series is got in decimals of an inch. Some of the screws so determined are illustrated in Fig. 5, Plate 111, magnified ten times full size.

Master Taps.—In order to originate and retain the standard, two sets of master taps are made: one set is used for making screw-dies, and the other is reserved for producing dies for making working-taps; both sets are in duplicate, one set of each being kept for reference only. The master taps are made on a small screw-cutting lathe specially designed for the work, having a corrected screw which can be depended upon for accuracy within practicable limits. The master taps for screw-dies are made to the exact standard; but those for tap dies are left sharper on the top, thus leaving them nominally larger in diameter than the standard. When the diameters are measured from the sides of the thread, both sets correspond with the standard; but the tap being larger than the screw, a space is left between the top of the screw-thread and that of the hole: that is to say, the female thread is deeper than the male thread. This space forms a convenient receptacle for any burr that may be present, but does not interfere with the fit of the screw in the hole. While in the soft, all the master taps are left slightly large, and without grooves. By hardening they become more or less distorted; this defect is corrected by grinding the threads by means of a soft steel lap charged with diamond dust; after which operation the longitudinal grooves are ground in. The grinding of the screw-threads is effected in the same lathe that cuts the thread. Instead of the cutting tool, a small and accurately made grinder is inserted in the tool-box of the lathe, and driven by a band through idler pulleys. A disc of soft steel, turned to the thread section and charged with diamond dust, is mounted on the end of the grinder spindle, and traverses along the screw in exactly the same way as the cutting tool. The longitudinal grooves are ground in by the

same arrangement, but of course the lap is of the proper section and runs vertically. An index on the lathe spindle gives the position and number of the grooves.

Dies.—The taps having been got as perfect as may be possible, the next step is to make the dies. These, as is well known, are inherently defective, as they stretch the metal and thus alter the pitch; but as yet no practicable substitute for them has been devised; all therefore that can be hoped to be done is to minimise their defects. Many attempts have been made to get nearer to cutting the thread, instead of squeezing it; but all such operations, when subjected to the inevitable wear and tear of daily use, have been found to result in more irregularity than the simple tapped hole, in consequence of the abrasion of the cutting faces of the dies, and their gradual loss of cutting power. These remarks of course apply to watch screws only, which do not exceed 0·050 inch diameter with a minimum of 0·010 inch. The die most in use therefore is simply a tapped hole, which for convenience is usually made in the centre of a small thin disc of steel. The disc is made small and thin, because the less metal there is surrounding the hole, the less is the distortion produced by hardening; and in addition, although the die is not split, yet the pressure exerted by the die-holder is sufficient to produce a slight modification in the diameter of the screw, provided the die is small enough; and it may be made small enough, because the die-holder is so designed as to prevent the die from bursting. This adjustment of the die in the die-holder is utilized to correct the alteration of size caused by hardening the die. After hardening, the dies usually open; so that they would leave the screws too large in diameter. The die-holder, which is a form of step-chuck, squeezes the die sufficiently to make up for this enlargement. When tapping the die, it is found best to mount it in a true step-chuck, and bore the hole true. A step-chuck is a chuck in which a recess or "step" has been turned in the face, of any required diameter. The chuck is then split longitudinally in three sections, and after being spring-tempered it is ground true. A conical portion behind the face corresponds

with the conical mouth of the lathe spindle; and the chuck closes when drawn into the spindle from the back, thus securing any article placed in the step or recess. The tail stock of the lathe carries the tap, and is provided with a traversing spindle, on which is fitted a feed-screw of the same pitch as the tap. When the tail-stock spindle is revolved, the tap is thereby fed into the die, and so leaves a more perfect thread than if the pitch of the tap itself were allowed to provide the feed. The tap dies are made in the same way; and both are used in the screw-making machines.

Screwing Machines.—Of these machines there are now many varieties, some purely automatic, others partially so, and others actuated by hand. As to the relative merits of each, now that the factory system of manufacturing large quantities of one sort of watch is in vogue, the purely automatic machines have the advantage. Of these there are many varieties, improvements being constantly made; and designs which a few years back would have been considered impracticable, owing to the difficulty of working to them, are now in daily use, as advances in the art of tool-making applied to watch machinery have been most rapid during the last few years.

Slitting.—A much debated point is the advisability of including the slitting of the screw-head in the operations performed by the screw-making machines. The addition of slitting mechanism certainly increases the liability of the machine to stoppage, as anything happening to the slitting mechanism necessarily stops the whole machine, and thus reduces the total number of hours per week that the machine would run without the slitting attachment. On the other hand the expense is entailed of picking up separately each individual screw, and putting it into a slitting machine; but upon so simple a job the youngest girls in the factory may be employed, and with a good slitting machine each girl can get through the product of three screw-making machines. Thus the advantage of doing the slitting in the screwing machine itself is at the best only slight; but however slight it may be, it cannot be despised.

Description of Screwing Machine.—In Plates 108 to 115 is shown a screw-making machine designed by the writer, which embodies most of the modern methods, and includes a slitting attachment. A description of this machine will therefore cover the principal features common to automatic watch-screw machines. Fig. 1, Plate 108, is a face view or front elevation of the machine, drawn one quarter full size; Fig. 3, Plate 109, is a plan; and Fig. 4, Plate 110, is a longitudinal section from front to back.

All screws are cut from the solid rod or wire. Four rods of any desired length are inserted in the hollow spindles S, Fig. 1, Plate 108, which are horizontal and parallel to one another; and the machine being then started works unattended until it has cut up the rods into screws, complete with slits, when it automatically stops, until four fresh rods are inserted; and the operation is repeated. The use of four rods, which is the distinguishing feature of the machine, renders it possible to have all the four tools in operation simultaneously. It is plain that turning down the shank by the first tool and screwing it by the second cannot be done together, where only one screw at a time is being operated upon; nor can the burr from screwing be removed by the third tool, and the parting cut be made by the fourth, until the screwing is finished. Therefore in machines working upon only one rod, three at least of the tools must be idle, while the fourth only is at work.

Lathe Spindles, Headstock, and Turret.—There are four hollow revolving lathe-spindles S, Fig. 1, Plate 108, carried horizontally in the main frame or headstock, which is a box casting. As shown full size in Fig. 6, Plate 111, each of these spindles runs in hardened and ground bearings, and is provided with friction driving-cones F, and automatic chuck. This combination allows of the rotation of the spindle being stopped at will, and also of the rod or wire being released when required, for feeding forward. The four spindles are driven by a belt which passes continuously round the driving pulley on each spindle in succession, Fig. 1, Plate 108. They are placed at equal distances apart, and concentric with a horizontal revolving turret T, upon which are mounted the four operating tools. This turret has a step by step rotation in the

direction of the arrow, through a quarter of a revolution at each step, thereby bringing the tools round into such a position that each tool acts successively upon each screw. In the position shown in Fig. 1, the first tool is turning down the shank of the screw in the lathe at the right-hand top corner; the second tool carrying the screwing die is cutting the thread on the screw in the right-hand bottom lathe; the third tool is removing the burr from the thread of the screw in the left-hand bottom lathe; the fourth tool has just given the parting cut to the screw in the left-hand top lathe; and in the centre of the turret this same screw is now having the slit cut in its head by the slitting saw, to which it has been brought by the quadrantal carrier Q.

Through the centre of the turret runs the cam shaft, Fig. 4, Plate 110, from which all the four tools are actuated; it is driven at a uniform speed by a worm and worm-wheel at the back end. One revolution of the cam shaft completes a screw; and the following quarter revolution is occupied in carrying the turret round through the next quadrant, when the operations of the four tools are repeated. Thus five revolutions of the cam shaft make four screws, a quarter revolution of the turret being utilized to open the chuck, Fig. 6, and feed the wire forward for the next screw. The opening of the chuck is effected by the cams CC, Fig. 1, carried on the turret, which strike in turn each of the four levers L pivoted on the main frame. These levers act upon other levers, which in turn are in contact with the face of the male friction-cone F, Fig. 6, driving the hollow spindle. A slight motion of the levers suffices to throw the friction cones out of action, and stops the lathe; and a still further motion of the levers pushes the friction cone against the spring-disc D, thereby releasing the grip of the chuck on the wire or rod. The arrangement which stops the machine when the rod or wire is used up is also actuated by the motion of the turret, as will be described later on.

Turning and Screwing.—The three turning tools are made in the form of circular discs, as shown in Fig. 1, Plate 108, turned on the periphery to the section required, so that they may be ground economically without spoiling their shape; circular cutters also go

back into the machine exactly, no resetting being required. These three cutters are carried on straight slides mounted radially on the face of the turret, and receive their feed directly from the three cams A, Fig. 4, through adjustable connections J, Fig. 1, which supply the means for setting the cutters so as to turn to the correct diameter. The screwing arrangement is connected with a cam B, Fig. 4, at the back of the machine, by means of a horizontal shaft running through the turret: in Fig. 7, Plate 112, drawn half full size, in which the turret is supposed to be transparent, it is seen that the cam is so shaped as to give a reciprocating motion to a pivoted quadrant, which is geared into a pinion on the shaft in the turret, and so gives a reciprocating rotary motion to the shaft; the latter is in turn geared to the die spindle E, as shown full size in Fig. 8, which thus receives a forward motion for running the die on to the screw, and a backward motion for running it off. The die spindle is also mounted in a sliding head H, which slides in a direction parallel to the axis of the screw. This sliding motion is controlled by a leading screw which is geared to the die spindle through a series of change gears, much the same as in an ordinary screw-cutting lathe. Thus the reciprocating motion of the quadrant not only imparts circular motion to the die, but through the change wheels and leading screw gives also a longitudinal motion corresponding with the pitch required.

Slitting Saw.—The slitting saw is carried in a frame G, Figs. 1 and 4, Plates 108 and 110, secured on one end of a rocking shaft which runs through the turret horizontally, parallel to the main shaft. On the back end of the rocking shaft is an arm carrying a roller, which engages with the slitting cam, as shown half full size in Figs. 9 and 11, Plate 113. The cam is so shaped as to give a slow forward rocking motion to the slitting frame, and a quick return. At the moment that the saw is cutting the slit, the saw spindle is approximately concentric with the turret; this arrangement is made in order that the driving cord shall not be affected by the revolution of the turret.

Screw Carrier.—The quadrantal carrier Q, Figs. 1 and 4, Plates 108 and 110, which conveys the screw from the parting tool to the slitting saw, has five distinct motions. It carries a split chuck, tapped to correspond with the screw. Normally the chuck is held closed by a spring I, Fig. 9, Plate 113, drawing it into a taper hole. When thus closed it runs on to the revolving screw, which has previously been nearly parted from the rod by the fourth tool. When the shoulder of the screw jams against the face of the chuck, it twists the screw off, and leaves it in the carrier, which is in the outer position shown in Fig. 9. The carrier then has a short horizontal longitudinal motion away from the lathe spindle, and a transverse quadrantal motion towards the slitting saw, assuming the inner position shown dotted in Fig. 9. After the short longitudinal movement is completed, and before the quadrantal movement commences, the carrier chuck makes a quarter turn on its arm, which brings it at right angles to the lathe spindle, and therefore ready for the slitting saw to act. After the slitting is completed, the motions are reversed; the carrier chuck first resumes its position parallel to the lathe spindle, and then returns for the next screw. During the return motion the chuck levers engage with a fixed cam K on the turret, thus opening the chuck, and thrusting the complete screw out of the chuck into a recess made for the purpose. All the movements of the carrier are got from two cams M and N, also at the back of the machine. The first cam M is a face cam, Fig. 4, which through a lever connection gives the short longitudinal forward movement; and the second cam N, Fig. 12, Plate 114, through a quadrant and pinion gives the turning and quadrantal movements. The turning of the carrier chuck, from a position parallel to the lathe spindle to one at right angles to it, is got from the rocking movement of the longitudinal shaft P in the turret. The carrier chuck is carried on the end of a second shaft Q, Fig. 9, parallel to the face of the turret, and mounted in a frame; this frame is carried on the end of the longitudinal rocking shaft P, and is free to revolve about the latter, while the carrier-chuck shaft Q is also free to revolve in the frame. The two shafts are connected by a pair of

mitre wheels. It is thus plain that any circular motion given to the longitudinal rocking shaft P must either rotate the carrier-chuck shaft Q or revolve the whole arrangement. In order to obtain each of these two motions in succession, two springs are planted on the turret so as to engage with the carrier frame. One of these at first holds the carrier frame, so as to prevent it from revolving; the longitudinal shaft P then revolves independent of it, and through the mitre wheels rotates the carrier chuck Q. When the chuck has made the necessary quarter turn, a stop R, Fig. 10, prevents any further rotation of the chuck shaft Q; and the pressure continuing, the holding spring is overcome, and the quadrantal movement travels the chuck inwards to the slitting saw.

Feed.—After each screw is taken from the wire or rod, the latter has to be fed forward through the lathe chuck through a sufficient distance for making another screw. The mechanism for effecting this consists of a hollow feed-chuck, Fig. 6, Plate 111, which passes into the lathe spindle from the back. The front end of this feed chuck has three longitudinal slots, extending about $2\frac{1}{2}$ inches in length, thus forming three spring-fingers closed in at the nose so as to grip the rod lightly. When the main chuck is gripping the rod more tightly, the feed chuck is pulled backwards by a cam and lever U, Fig. 4, and slips along the rod. As soon as the main chuck opens, the feed chuck springs forward, carrying the rod with it. The opening of the main chuck takes place during the quarter revolution of the turret; and the wire springing forward abuts against an adjustable stop W, Fig. 1, carried on the turret. This stop is planted in such a position on the turret as to continue opposite the end of the lathe spindle all the time that the chuck is open. When the feed stop W has passed over the end of the lathe spindle, the wire projecting from the face of the chuck engages with the tail of a click V, and so prevents the click from catching in a loose concentric ring Y, Fig. 12, Plate 114, immediately at the back of the turret. This loose ring is connected by levers to the striking gear of the countershaft. If the click V were not held away from the loose ring, it would engage in one of four slots or notches cut across the inner rim of the ring, and so would carry the ring round with the turret, thereby throwing

the strap upon the loose pulley. When the rod is all used up, no wire is fed forward; the click V being therefore not held away engages in the loose ring Y, and the machine stops.

Rotation of Turret.—The means by which the step by step rotation is given to the turret, through a quarter of a revolution at each step, is shown one-third full size in Figs. 13 to 15, Plate 115. The locking slide S, carried in a radial recess in the body of the turret, has a **V** shaped notch in its outer end, for engaging successively with each of the four radial taper stops T in the headstock, towards which it is pressed outwards by a spring at the back. In each revolution of the main driving shaft the cam C strikes the lug L on the inner end of the slide, and draws the slide inwards, clear of the stop T, Fig. 14. In this position it is held back by the nose of the side click K, against the outward pressure of the spring, after the tip of the cam C has cleared the lug L. The opposite cam D now comes against the lug G, and carries the slide and turret round through a quarter of a revolution to the next stop T. Just before reaching this position, the tail of the click K, Fig. 15, striking against the stop, releases the slide, which is immediately thrown into action by the spring, and again locks the turret in its new position, while the main driving shaft makes another complete revolution.

Slit.—The width and shape of the slit in the screw head are not unimportant matters. Until recently it was usual simply to run a saw through the screw heads, thereby forming a slit with parallel sides; whilst for the better classes of work the external corners of the slit were filed off during polishing, in order to retain the good appearance of the screw, because otherwise the screw-driver bore against the sharp edges and threw up a burr. It is now customary to make the slits of a width proportional to the diameter of the thread, and to use a cutter whose sides are inclined to the centre line at an angle of about 5°, or 10° over all.

Screw-driver.—It was also found necessary to wage war against the "handy" screw-driver, which was mostly made from the first piece of steel picked up; and a pair of flats were then filed on it in the

usual hurry. Screw-drivers are now made with standard taper holes and loose tapers, the latter being made economically in large quantities to the same taper as the slit. If a screw-driver breaks down, a new taper is at once inserted; a frequent cause of botching is thus removed. The screw-drivers are designed so that no more power can be used than is just enough to drive the screw home; and the narrowness of the slit prevents a large and powerful screw-driver from being used on a small screw.

Polishing.—The methods of polishing are various, and depend largely upon the style and quality of the watch for which the screws are intended. If flat heads are required, two or three hundred screws at a time are mounted in a series of holes in a plate, and are ground and polished on a vertical grinding mill, which in appearance is much like an ordinary drill-press; but the bottom table revolves and is placed eccentrically to the top spindle. The latter is weighted so as to exert a downward pressure on the bottom table; and carries an arm fitted with a male centre, which is put into a corresponding female centre in the back of the plate of screws, thus pressing the screw-heads down upon the bottom table, which is supplied with polishing material. The motions of the arm and table are always in opposite directions; and the two spindles are so arranged that each part of the whole surface of the bottom table has contact with the screws in turn. Where round heads are required, the screws are put into holes drilled radially into a half sphere on the nose of a lathe spindle, and are then ground and polished, which gives them a spherical contour. Many machines are also in use for doing the screw-heads separately; these undoubtedly give the best results, because any burrs left from the slitting are more effectually removed. When screw-heads of slightly conical shape are required, they are economically formed by polishing three together. Each screw is mounted in a separate spindle, three of which are arranged in the form of a triangle; then by throwing the spindles out of parallel, or by varying their length, and by using a polishing disc which adjusts itself on all three, the desired conical head is obtained.

Conclusion.—For introducing so many small details into this paper the writer's excuse must be that these seeming trivialities have an obstinate habit of taking up a most uncompromising attitude, and blocking the road which leads to success. The modern watch-factory is indeed the result, not so much of a brilliant effort of genius, as of the perseverance of many minds persistently bent on carrying their ideas to a successful issue.

Discussion.

Mr. Hewitt pointed out that in the drawings of the machine the four spindles were placed in the corners of a square, of which the sides were horizontal and vertical; but in the machine now shown that arrangement had been altered by shifting the spindles through 45°, so that they were here placed in the corners of a square of which the diagonals were horizontal and vertical. The object of the change was to suit the driving tackle, which in a watch factory was nearly always placed overhead; and this machine had to be driven from overhead. The design shown in the drawings had been got out for the machine to be driven from underneath. The alteration did not involve any change at all in principle, being simply a matter of detail. Another alteration was that, instead of the turret receiving its quarter revolution through the cam shaft, as described in the paper and shown in the drawings, an additional worm and wheel were introduced with the object of revolving the turret independently of the cam shaft. This wormwheel was cut on the periphery of the turret, and was actuated by a worm fixed upon a shaft which was driven by a round band in a grooved pulley. When the turret was locked at rest, the band slipped on the pulley; and when the unlocking cam released the turret slide, the turret revolved at a slightly slower rate than the cam shaft. This difference of speed gave the unlocking cam time to get out of gear with the lug

on the slide, thereby allowing the slide to engage with the next stop, which locked the turret securely until the cam shaft had made a complete revolution and had again released the locking slide. The object of this alteration was to relieve the excessive strain that was put upon the cam shaft and its worm and wheel in releasing the chucks during the revolution of the turret.

The President observed that the subject of the paper raised a considerable variety of questions, connected not only with the highly ingenious and elaborate machine now exhibited, but also more generally with the standardizing of very small screws.

Mr. Thomas Buckney, having had the honour of serving on the screw-gauge committee of the British Association in 1882–4, congratulated the author on having adopted the British Association threads, which he believed he had himself been the first manufacturer to use. The present threads had been originated at the instigation of Mr. Preece, who had been the president of the committee; and he believed it was in order to supply the wants of the Post Office that the committee had been appointed. The Post-Office authorities had experienced great inconvenience in their telegraphic instruments from the multiplicity of the pitches of the screws, and they thought it would be highly desirable to have a uniform gauge. Although he had himself been in the minority in not agreeing altogether with the decision arrived at by the committee, he had loyally accepted their decision. He should much have preferred the adoption of the Whitworth form of thread, and the British inch as the unit of measure. The committee however had adopted the metric system, and there was nothing to do but to bow to their decision. He had used these screw-threads for a number of years, and was perfectly satisfied with them. The series was an exceedingly good one. The screws were strong, useful, and readily made; and as far as he knew they were better than any that had preceded them. The screws he was using had been originated he believed at the expense of the Post Office, and had been made by Mr. Lehmann, who at one time had been foreman or works manager to Mr. Stroh. In

(Mr. Thomas Buckney.)
originating these threads Mr. Lehmann had been extremely careful and painstaking, and had certainly produced a very good series of threads. He had not been aware that any other screw manufacturer had originated these threads independently, until he learned from the paper that the author had done so. It would be exceedingly interesting he thought to compare the two sets of screws thus worked out independently, and to see whether the pitches and sizes were identical; the size was of course much more easily measured than the pitch. The system of screws adopted by the British Association committee he believed was practically that arranged by Professor Thury of Geneva; for the gauge at present in use, known as the British Association gauge, was almost identical with the gauge which had been introduced by a Swiss committee presided over by Professor Thury. The latter gentleman had followed the same course that Sir Joseph Whitworth did: he had collected a great number of screws from the best makers, and had established a gauge based on the screws most generally used, so far as regarded the pitches for the various sizes of screws. The British Association committee had practically adopted his system, making only a small difference in the shape of the thread. In Professor Thury's thread the bottom of the thread of the tap was rounded out with a smaller curve than the top, the object being to give the thread of the nut additional strength. As a matter of fact, in the small instruments for which those screws were designed and were in use, there was practically no nut. The screws themselves were generally tapped into some plate of the instrument itself. The so-called nuts or holes therefore could not be replaced; and it was consequently thought desirable to give the base of the thread that larger rounded form, with greater strength than in the screw, so as to resist wear longer, because a new screw could be put in much more easily than a new plate. The British Association committee had adopted a rounding which was equal at the top and the bottom of the thread; that was the only difference they had made, he believed. The pitch was referred to the diameter by the same formula; the angle of inclination of the thread was the same; and beyond the alteration in the rounding of the thread he himself saw

no difference. In the Whitworth thread the angle of inclination was 55°, and in the Swiss thread and the British Association thread 47½°. In the Whitworth thread one-third of the height was rounded off from the triangle which would be formed by the thread, namely one-sixth at the top and one-sixth at the bottom, leaving the depth of the thread about two-thirds of the pitch. In the Swiss thread the depth was three-fifths of the pitch; the top was rounded off with a radius of one-sixth of the pitch, and the bottom with a radius of one-fifth of the pitch. In the British Association thread both the top and the bottom were rounded off with a radius equal to two-elevenths of the pitch.

The taper slitting of the screw heads he thought was a decided improvement (page 484). He had himself slit screws with a parallel saw, and used a screw-driver, which was not exactly a taper, but was slightly hollowed out on each face so as to get the part almost parallel that went into the screw slit. The taper slitting of the screw heads seemed to him to be an improvement of great importance. There appeared to be an immense amount of ingenuity in the machine described in the paper, and he had no doubt that it performed its work well, otherwise it would not have been now exhibited for examination.

The grinding of the screw-threads, or the polishing of the threads of the tap, was stated in the paper (page 476) to be effected in the same lathe that cut the thread; but instead of the cutting tool a small and accurately made grinder was inserted in the tool-box of the lathe, and driven by a band. The edge of such a revolving grinder must of course have some inclination depending upon the pitch of the thread; and it appeared to him that by its revolution it must distort the thread to some extent. It would indeed move forward according to the pitch of the screw; but the inclination or angle of the pitch at the bottom of the thread was different from that at the top of the thread. If a mean were adopted by taking the inclination at the middle of the thread as the angle of inclination for the grinder, there would be a slight error at the top and bottom of the thread; and he should like to know how that difficulty had been overcome.

Mr. James E. Darbishire asked whether any of the screws were tempered or hardened after cutting, and if so whether the thread was distorted thereby. He did not know whether it was the practice in watch-making to harden the screws; and if it were, it would be interesting to learn to what extent the thread would be altered in the process.

Mr. Bryan Donkin thought it would be interesting to know the number of revolutions made by the machine per minute, the output per minute for certain sizes of screws, the average speed for the different sizes, and how many machines were at work.

Mr. William Taylor said his interest in screw-making had been in connection with larger screws than those with which the manufacture of watches was concerned. As a member of the standards committee of the Photographic Society of Great Britain he had been interested in securing amongst makers of photographic lenses the adoption of common standard screws for the attachment of their lenses to cameras; and as a manufacturer of lenses at his firm's works in Leicester he had taken an active part in developing appliances for securing free interchangeability, real and effective, of the screws made for that purpose. For photographic lenses, as in the case of the smaller screws for watches, it was necessary that the screws should always go together without the need of applying extra force. The problems involved in securing such free interchangeability of screws were really complex; but the condition upon which the free interchangeability of screws depended was simple. There was indeed one condition alone: namely that every male screw should be at least as small as the standard, and every female screw at least as large as the standard. The title of the paper had led him to hope that the author would have said a good deal more about his methods of originating these forms of thread, and of measuring them; because on a real and true understanding of the methods of originating and measuring forms of thread would depend the success realised in securing free interchangeability of screws. Electrical and optical instrument

makers, a large and important body of manufacturers who had adopted the British Association screws, well knew from experience the great difficulty of getting really interchangeable screws. So far as he had heard, they generally complained that the screws varied in size sufficiently to introduce the difficulty that, when a hole which might fairly be considered a standard hole had been tapped in a piece of metal, nominally standard screws might be met with, which required extra forcing into that hole. The system which he had developed at his firm's works at Leicester of securing free interchangeability amongst screws depended on the principle just defined, that every male screw should be at least as small as the normal size, and every female screw at least as large as the normal. For better illustrating the way in which this was done, he had brought one of the standard screws for lens fittings, nominally two inches full diameter, which was cut in the way that all the screws were cut at Leicester, to fit the flat calliper gauge exhibited. This was seen to be a double calliper gauge, as shown full size in Fig. 19, Plate 116; after it had been hardened, the space between the jaws FF on one side had been ground out accurately to two inches, and the space between the jaws SS on the other side to exactly one-thousandth of an inch less than two inches. The workman who cut the screws had to make each pass through the gauge on the side F that measured two inches, without any jamming whatever; and it must not pass through the other side S. In that way all the screws were made correct to one-thousandth of an inch, on a principle which secured free interchangeability, provided sufficient care had been taken to ensure that the form of the thread was correct. With this sort of calliper gauge the diameter of the screw was measured only on the crests of its thread; and if steps were taken, as could be done, to ensure that the form of the thread should be correct, or at any rate that the thread should be slightly too thin rather than slightly too thick, a screw was attained which was perfectly and truly interchangeable with other standard screws similarly made. As a proof that this system of working was satisfactory, it might be mentioned that his firm had had it in use about three years, and had made in this way thousands of screws,

(Mr. William Taylor.)

which when fitted together must have formed many millions of combinations; and never once had a case been reported of two screws failing to come together freely, and never had there been an amount of shake exceeding two-thousandths of an inch. Apart from such minute work as standard screws for machine-made watches, or even the larger screws he had mentioned for photographic apparatus, it appeared to him that, if in common bolts and nuts perfect interchangeability were ever going to be attained, this could be done only by working on the principle he had defined. Having attended the recent summer meeting of the Institution in Manchester, he had had the good fortune to be one of the visitors to Prescot who were shown round that highly interesting factory by the author of the paper; and he could bear his testimony to the wonderful skill displayed in designing not only the machine now described and exhibited, but also a large variety of other tools almost as complicated. How such a vast amount of work had been done he could not understand; and he should much like to know something of the way in which the author had managed to get through it all.

The President asked what were approximately the pitches and other dimensions of the threads in the photographic screws, in order that these might be compared with those in the watch screws.

Mr. Taylor replied that the series of screws originated by the standards committee of the Photographic Society were based on the English inch, with the Whitworth form of thread, and varied in diameter from one inch, which was the smallest, up to any size. The diameter advanced from 1 inch by quarters of an inch up to $2\frac{1}{2}$ inches, then by half an inch up to 4 inches, and onward from that diameter by inches. The pitch of the screws in all the sizes smaller than $3\frac{1}{2}$ inches diameter was constant, namely twenty-four threads to the inch; for $3\frac{1}{2}$ inches and all larger diameters the pitch was twelve threads to the inch.

About the degree of accuracy obtained in forming the screw taps, not much had been said in the paper; and from his own experience he considered it was not at all a simple matter to originate a screw

thread correctly in respect to its form. In forming the chasers with which his screws were cut, he was content if the chaser was correct to one ten-thousandth of an inch. This was for work however which was comparatively coarse ; and for watch screws he presumed that greater accuracy was obtained. This was a highly important matter ; because, although it was comparatively simple to make screws interchangeable in any one factory, it was a different thing to make screws interchangeable in different factories when the only means of comparison lay in original standards of length, and there was no means of comparing the taps and the other actual embodiments of those standards.

Sir Frederick Bramwell, Bart., Past-President, had no doubt the practice of making female screws to the full size and male screws to the bare size would always ensure interchangeability (page 490) ; but he should be glad to know whether it would ensure tightness in the screw. Would a screw so made be a good fitting screw?

Mr. Taylor explained that, in speaking of the principle on which free interchangeability of screws was to be secured, he had intended to lay stress on the adjective "free." What was wanted with such screws as those used for photographic lenses was, that they should never require forcing together with wrenches or tongs; and in order therefore to secure free interchangeability it was provided that every male screw should be at least as small as the standard and every female screw at least as large. On the other hand, in order to limit the objectionable shake which would occur if every male screw were made much too small, a limiting gauge was used. The male screw was never made more than one-thousandth of an inch too small in diameter, and the female never more than one-thousandth of an inch too large: so that when the two screws were put together, the utmost shake that resulted would not under the most unfavourable circumstances be more than about two thousandths of an inch.

Sir Frederick Bramwell feared he had hardly appreciated the fact that the screws referred to were to be made of large diameter for

(Sir Frederick Bramwell, Bart.)
the purpose of lenses. He had been thinking rather of the use of screws for the purpose of holding work together.

Mr. S. Zachary Lloyd asked if the author had had any difficulty in securing exact accuracy in the number of threads per inch, in cutting them with a die. In Messrs. Nettlefolds' screw works he had found that in cutting fine threads for taps, if they were cut with a die, there was a liability to putting a slight strain upon the threads, causing a slight variation in the number of threads per inch. Even the reversing of the die, it was supposed, would occasionally affect the thread to some extent. On this account it had been found necessary to cut the threads with a single cutter, in preference to cutting them with a die. It would be interesting to know whether the same difficulty arose with an automatic machine like that now exhibited; or whether the automatic action was so accurate that the difficulty did not arise. He had not had much practical experience of screws of so small a size as those for which this machine was designed; in fact this machine began where the sizes in Messrs. Nettlefolds' works left off. In those works the British Association thread was now being adopted for all sizes below 1-8th inch diameter; and for 1-8th inch and upwards the Whitworth thread was used. So far this plan had been found to answer well for dealing with the different sizes. The machine now exhibited however was an entirely different class of machine from those used by his firm; the latter were used solely for cutting screws from blanks previously headed, which of course was an altogether different system from cutting them entire from straight wire in a turret lathe of the kind here shown.

Mr. David Joy thought the machine now described was perhaps one of the most beautiful and elaborate that had ever been brought before the Institution; and he imagined that its construction would require the utmost exactness and certainty. Some of the motions, at any rate the return motions, he noticed were produced by helical springs, and not by direct or positive action. In his own experience with steam machinery, he had had little to do with such springs, and

had rarely seen any work done by them, except in the safety-valves of steam engines. He should be glad to know whether the helical springs used by the author were found to answer best in compression or in extension; and how far they could be relied upon for keeping in perfect and accurate action. In steam machinery it was not customary to place any trust in helical springs, except for safety-valves, for which that kind of spring proved a splendid servant.

Mr. C. Frewen Jenkin asked what arrangement there was in this machine for taking up the slack which invariably arose after a machine had been working for a length of time. In other turret lathes that he had seen the great difficulty in the way of obtaining accurate work had been to provide for taking up the wear of the machine itself. In the drawings there did not seem to be any indications of how this was done.

Mr. James Stabler asked what number of screws per minute could be turned out perfect by the machine exhibited.

Mr. Hewitt understood that the angle of 55° in the Whitworth thread, Fig. 18, Plate 116, would have been preferred by Mr. Buckney (page 487), instead of the angle of $47\frac{1}{2}°$ adopted by the British Association, Fig. 16. With that preference he did not himself quite agree; for he thought that the thread of $47\frac{1}{2}°$, having the top and bottom rounded with a radius equal to two-elevenths of the pitch, thereby leaving a strong top and bottom to the thread, was more suitable for watch-making purposes.

In the grinding of the thread (page 476) it was not pretended that the result of the operation was perfection. The best that could be done was not perfect, and it was necessary to submit to something which was far short of what he should like it to be. As pointed out by Mr. Buckney (page 489), the method of grinding the thread was theoretically incorrect; but it corrected difficulties which were greater than it created, and therefore it was used.

In regard to limiting gauges (page 493) and the preservation of the standard for taps, a system of limit gauges was adopted, not only

(Mr. Hewitt.)
for screws, but all through the Prescot factory, for cutting toothed wheels and pinions, and for diameters and everything else. Although absolute perfection could not be obtained, the limit of inaccuracy was only about 1-2,500th of an inch. It would be going too far to attempt to get absolute perfection in watch-making, because the product had to be considered from an economical point of view. The best that could be done was an approach to within about the above limit, that is, four ten-thousandths of an inch; and this had been adopted right through the factory as a standard of accuracy, applying to screws as well as to everything else. This inaccuracy was kept a minus quantity, that is the screws when not correct were 1-2,500th of an inch less than the standard; but even when the error was on the plus side, that is when the screws were 1-2,500th of an inch too large, they would still enter the holes, owing to the fact that the female thread was deeper than the male. This forcing of the screw into the hole was of course undesirable; therefore the error was kept on the small side.

The number of screws the machine would make (page 495) depended somewhat upon their size; it was designed to make an average of 6,000 screws per day of ten hours. The machine could be run more quickly than that, but it was not advisable.

As to the helical springs (page 495), with the exception of the chuck springs they were always used for return motions only, and were not intended to do any driving work, but only to return the slides, racks, and pinions to their original positions. It would be noticed that this principle had been adhered to in the design of the machine exhibited. Helical springs were always used wherever possible; and when practicable were used in compression in preference to in extension. When they were used in compression they were always put in a hole, and a steel pin with a projecting head was inserted along the centre of the spring to hold it in position. The chuck springs, as shown in Fig. 6, Plate 111, were instances of springs in compression, and were the sole exceptions to the statement that the springs did only return-work. These springs closed the chuck direct; and the requisite power was got by multiplying the number of the springs, in preference to increasing the thickness of a single spring.

The difficulty referred to by Mr. Lloyd (page 494), of keeping the threads to the exact pitch when using a die, was a serious difficulty if the die was not guided; but if there was a mechanical method of guiding the die on the screw, the defect was minimised. The difficulty could not be altogether got rid of, and there was a considerable amount of inaccuracy even in those screwing machines in which the die was guided on the screw. In the machine exhibited the die was geared to a traversing or leading screw, much in the same manner as in a screw-cutting lathe. In that way the die was mechanically guided, the difficulty was minimised, and the screws were better cut in that fashion than in any other. The net result of this error was that the length of the holes had to be kept within reasonable limits. For instance holes that were $1\frac{1}{2}$ diameters long would receive the large proportion of screws; but occasionally a lot would come round, which caused trouble. The latter was no doubt due to the variation in the quality of the metal from which the screws were made. When the holes did not exceed one diameter long, no difficulty was ever experienced.

Mr. John Phillips asked whether the screws were cut dry, or whether any lubricant was used. Also whether there was any heating arising from the cutting.

Mr. Hewitt replied that oil was pumped freely upon the cutting tools during the whole time that the machine was at work. Heating was a slight matter in such small work, and was largely eliminated by the oil used so liberally.

Mr. James Haswell enquired whether the American watch factories also used the British Association standard screw-thread.

Mr. Hewitt was not certain, but believed they did not.

The screws were hardened after cutting (page 490), and the distortion from hardening was so slight in such a small length of screw that it was never appreciated.

(Mr. Hewitt.)

With regard to taking up the slack in the machine after lengthened working (page 495), no provision of that sort had been made in this machine, because all the bearing surfaces were hardened as hard as fire and water could make them, and were then ground, and afterwards stoned, so as to get the grinding marks out of them and give them a perfect surface. One of the spindles had been taken out of the machine and was shown separately, in order that it might be handled by any one who desired to see the way in which the bearings were got up. When so prepared the spindles could be run for a considerable time without any apparent wear; and therefore no arrangement for taking up the slack was needed.

The machine as arranged made only one size of screw, on which it was kept at work; and it was not supposed to be changed to another size. The machine exhibited was fitted up for making balance screws of 0·017 inch diameter and 231 threads per inch. It could be fitted to cut any size up to 0·070 inch diameter, which was the maximum watch-screw; and with more extensive arrangements it could be fitted for cutting screws up to $\frac{1}{4}$ inch diameter and $\frac{1}{2}$ inch long. For any larger size a larger machine would be required.

Mr. Lehmann's origination of the standard taps and screws for the British Association had been mentioned by Mr. Buckney (page 488); and having brought with him a set of taps which had been made at the Prescot Watch Factory, as described in the paper, he should be happy to hand them over for comparison with the taps made by Mr. Lehmann, in order to see how nearly they might be found to agree.

The President said such a comparison would be extremely interesting, and he hoped the result would afterwards be communicated for the information of the members. If two English manufacturers had independently managed to originate separate sets of taps for screws from one hundredth of an inch diameter upwards, and those taps made interchangeable screws, he thought it would be one of the finest things that English manufacturers had ever done.

Mr. Arthur Le Neve Foster, having been a member of the British Association committee, mentioned that the British Association

thread had been originated by most of the principal electrical firms; and the firm of screw manufacturers with which he was connected had originated all their own standards. Having had the opportunity of comparing a number of these standards, he had found that they agreed fairly well. Both the Post Office and the War Office he believed could say the same.

The President was sure the members would join in giving Mr. Hewitt a most hearty vote of thanks for his admirable paper. It was not only a record of extremely careful work, but also a most detailed record of the manner of working what appeared to him to be one of the most ingenious and complete machines for doing complicated work that had been brought before the Institution. From the study of the paper and of the elaborate drawings by which it was illustrated, he had no doubt the members might imagine how great must have been the difficulty of actually arranging the details of the machine itself.

Mr. H. W. Jones, Manager of the torpedo factory, Woolwich, wrote that, although the paper dealt only with the limited range of screws pertaining to the particular industry of watch-making, much of what was therein advanced was applicable to the wider scope in which was contemplated the establishment if possible of one uniform standard for all forms of binding screws. When commencing operations at the Lancashire Watch Works it may well be imagined that some difficulty may have been experienced in selecting the special class of screw suitable for this manufacture, owing to the absence in this country of any generally accepted standard for small sizes of screws; and it will probably be admitted that the adoption of the modified Swiss standard recommended by the committee of the British Association in 1884 was a wise course. The author is to be congratulated upon the fact that he had a free hand in this direction at the initiation of the manufacture; and was thus enabled

(Mr. H. W. Jones.)
to select the particular kind of screws required, without being trammelled by outside conditions. As an illustration of the inconvenience entailed where such conditions are imposed, it may be mentioned that, when it was decided some twenty-one years ago to adopt the automobile torpedo, a sample weapon was ordered and supplied from the foreign factory at Fiume, the only source from which these torpedoes could then be obtained; and it was discovered that the pattern torpedo contained a variety of sizes of small screws, all more or less of a bastard character, not conforming with any recognised standard. Nevertheless the reception and approval of this pattern torpedo necessitated the adoption of these objectionable screws for all future supplies; and when the manufacture of torpedoes of different designs and patterns was commenced at Woolwich, these illegitimate screws were notwithstanding continued, in order to avoid multiplying patterns and sending out into the navy screws of the same diameters but with different pitches. Indeed even in the present manufacture of torpedoes the adoption of any standard for screws, with a view of its becoming recognised as universal, would be precluded for the same reason. The torpedo of twenty years ago was a primitive machine compared with what it is at present. During this period it has developed into an extremely beautiful and refined piece of mechanism, involving in each weapon a large number of small screws. In the 18-inch torpedo there are about 600 screws, ranging in diameter from 0·078 inch up to 0·314 inch, all of which have to be perfectly interchangeable with others at remote stations in every quarter of the globe. No margin is allowed for looseness in fit, but it is necessary that each screw should fit its nut or seat without any shake or play whatever; otherwise, owing to the vibrations set up in the torpedo when running at high speed, the screws would shake out, and the result would be a lost shot. The smallest of the torpedo screws exceeds in diameter the largest mentioned in the paper (page 477); and even if it were possible now to start afresh from the very commencement, it would be difficult to find a uniform standard for the range of torpedo screws, owing to the non-existence at present of any satisfactory standard ranging between 0·236 inch diameter, which is the maximum of the Swiss scale,

and the half-inch diameter in the Whitworth code of engineers' screw-threads. While the latter system is generally satisfactory for diameters above half an inch, the writer believes it is decidedly the reverse for screws below that size; and he thinks it would be highly desirable to originate a new standard for all screws between 0·236 inch and 0·500 inch diameter.

However satisfactory the four-spindle screwing machine may prove in the author's works, the increase in number of parts, in prime cost, and in wear and tear, together with the constant adjustments likely to be needed, leads the writer to fear that not much superiority may ultimately be found over the single-spindle machines. The screwing machines preferred at Woolwich, which have given the most complete satisfaction there, are those of the Hartford Machine Screw Co., made by the Pratt and Whitney Co., U.S.A. These machines are extremely simple, and cheap in first cost; while with ordinary attention to dies and cutters their production is everything that can be desired, so far as the screws required for torpedo manufacture are concerned.

Mr. Hewitt considered Mr. Jones' communication most interesting (page 499), as showing how universally mechanicians are confronted with the screw problem, and what difficulties attend any change of standard. At the Lancashire Watch Works the adoption of the British Association standard, Fig. 16, Plate 116, was found to be by no means an easy matter. On the formation of the works the existing watch-movement manufacturers were amalgamated, with the intention of carrying on their existing businesses and gradually merging them into one establishment for complete watch-making. As the movements of Messrs. Wycherley Hewitt and Co. had become the recognized standards, these were adopted, and the other movements were brought into line with them. The manufacture of these movements proceeded for some time, until in fact many thousands had been made and sold, before the necessity for a revision of the screw standard was forced upon the author's firm. Thus the same difficulty as that experienced at Woolwich was felt by themselves; nor does the author think they could ever have adopted the

(Mr. Hewitt.)
British Association standard except for the fact of its having been based upon the screws most generally in use in the watch manufacture. This enabled them to choose screws so nearly corresponding with those hitherto used that the new series could be utilized for jobbing purposes.

Curiously enough the Woolwich experience of screws ranging from $\frac{1}{2}$ inch to $\frac{1}{4}$ inch diameter is exactly the same as that of the author's firm. The latter have been forced to the conclusion that the Whitworth pitches below $\frac{1}{2}$ inch diameter are too coarse; and for tool-making purposes they have in consequence adopted a standard which better suits their requirements. The accompanying table (page 503) gives the dimensions of this series. The diameters are all in hundredths of an inch, which gives the advantages of the decimal system and a convenient and sensible designating number. The shape of the thread is a V of 60 degrees, sharp both at top and at bottom. The pitch of this series is all that could be desired; but the form of the thread is not altogether approved by the author's firm. They would have preferred to use the British Association thread for all their screws, had the committee recommended the adoption of the negative or ascending series, Fig. 17, Plate 116, in which the pitch is expressed by the same constant $0 \cdot 9$ mm. raised to the powers of -1, -2, -3, &c., and the diameters by the same formula * as in the paper, namely $D = 6\,P^{\frac{6}{5}}$. The thread is triangular with a vertical angle of $53^\circ\,8'$, which gives a triangle whose perpendicular is equal to its base. The top and bottom are truncated through one-eighth of the height with a radius equal to $0 \cdot 1011$ of the pitch. In this series the pitch corresponds closely with those generally approved, such as the Whitworth, Fig. 18; but owing to the fact of its being founded upon a rational theoretical basis, there are none of the irregularities and inconsistencies that are met with in other series. This series of screws therefore is suitable for watches, clocks, and electrical apparatus, as well as for machine building and the largest engineering work. The great objection to its adoption is the fact of its being based upon the millimètre, which is an insuperable obstacle,

* That is, the diameter is equal to the product of six multiplied by the sixth power of the fifth root of the pitch.

unless the inch be abandoned and metric measurements adopted. Theoretically millimètres can be converted into inches; but the measurements then become so fractional as to entail much loss of

Dimensions of Standard Screws with Flat Heads.

Diameter at Top of Thread.	Number of Threads per inch.	Diameter at Bottom of Thread.	Diameter of Drill for Cast-iron.	Head of Screw.		
				Diameter.	Length.	Width of Slot.
Inch.	No.	Inch.	Inch.	Inch.	Inch.	Inch.
0·04	160	0·0292	0·033	0·06	0·04	0·006
0·06	112	0·0446	0·050	0·09	0·06	0·010
0·08	84	0·0594	0·067	0·12	0·08	0·013
0·10	68	0·0745	0·083	0·15	0·10	0·016
0·12	56	0·0891	0·100	0·18	0·12	0·020
0·14	48	0·1040	0·117	0·21	0·14	0·023
0·16	42	0·1188	0·133	0·24	0·16	0·026
0·18	40	0·1368	0·150	0·27	0·18	0·030
0·20	36	0·1519	0·167	0·30	0·20	0·033
0·22	32	0·1659	0·183	0·33	0·22	0·036
0·25	28	0·1882	0·208	0·375	0·25	0·041
0·30	24	0·2279	0·250	0·450	0·30	0·050
0·35	22	0·2713	0·292	0·525	0·35	0·058
0·40	20	0·3136	0·333	0·600	0·40	0·066
0·45	18	0·3538	0·375	0·675	0·45	0·075
0·50	14	0·3763	0·417	0·750	0·50	0·083
0·55	13	0·4168	0·458	0·825	0·55	0·091
0·60	13	0·4668	0·500	0·900	0·60	0·100
0·65	12	0·5058	0·542	0·975	0·65	0·108
0·70	11	0·5426	0·583	1·050	0·70	0·116
0·75	10	0·5768	0·625	1·125	0·75	0·125

The dimensions given in the last five lines are added only for occasional use; screws slotted for screw-drivers are rarely required larger than 0·50 inch diameter.

(Mr. Hewitt.)
time both in the drawing office and right through the works. Considering that the British weights and measures are little better than a relic of barbarism, and must sooner or later give way to some decimal system, and that the metric system is now well established and is perhaps as good as any other decimal system which might be evolved, the author's firm would most assuredly have adopted the British Association series, making all measurements in millimètres, if the committee had seen fit to recommend it. As it was, they preferred to wait the development of events.

Having had the good fortune of inspecting Messrs. Pratt and Whitney's works in Hartford, Connecticut, and having also many of their machines in the tool room of the Lancashire Watch Works, the author can fully endorse the Woolwich experience as to the merits of their screw-making machinery. The machine described in the paper he is confident will pass unscathed through the ordeal, only too trying, of lengthened experience: firstly, because up to the present time it has justified all his expectations; and secondly, because many turret-machines, constructed much on the same lines for kindred purposes, have already been in daily use for some years, and have proved most advantageous. As explained in a paper read before the British Association on 15th September 1893 by Mr. Thomas P. Hewitt, the objections offered by Mr. Jones to a four-spindle screwing machine have been anticipated by so designing the turret rest as to render the accuracy of the work almost independent of ordinary wear and tear. In fact before the improvements now effected were introduced, the turret rest could be used only as a roughing-out machine; but already some dozens of them are doing the most accurate work possible, and doing it most speedily.

While fully recognizing the advisability of simplicity in all machinery, the author would remark that simplicity is only a relative term and may become misleading. For instance in the Prescot factory there are six single-spindle screwing-machines making together an average of 80,000 screws per week, inclusive of stoppages for re-setting &c. When these machines were introduced they were considered so complicated that they were in danger of

being condemned untried. But subsequent experience with still more elaborate machinery has now made these earlier machines appear not merely simple in comparison, but also quite behind the times, as indeed they are. Thus complication today may be looked upon as simplicity tomorrow; and the author's experience leads him to conclude that no machinery is so good that nothing better can be desired.

DRILLING MACHINES FOR CYLINDRICAL BOILER SHELLS.

By Mr. SAMUEL DIXON, of Manchester.

Origin of Drilling of Boiler Plates.—The introduction of steel plates into the construction of Steam Boilers and other riveted work brought with it such an entire change in the processes of construction as to amount almost to a revolution in boiler making. In no branch perhaps is this so striking as in the Drilling of all rivet holes which were formerly punched. The liability of steel plates to injury in the process of punching was early recognised in this country; and it was largely due to the foresight of the late Mr. Daniel Adamson that the problem was fairly faced, which at that time threatened to be almost fatal to the use of steel for boiler construction. So rapid and complete has been the development of machinery to cope with this most pressing necessity, that boiler makers now feel but little or no anxiety on the general question ; and are enabled to give attention to some of the minor points, such as the details of construction of the various machines, and the wear and tear of the parts which come against the cost of work. The chief factor in Boiler Drilling Machines however remains, as it has been from the beginning, the amount of work produced by the machine. Having regard to the symmetrical arrangement of the holes in the circular and in the longitudinal butt seams of boiler shells, the operation has from the outset appeared to be one in which the employment of a number of drills, all operating at the same time, seems the most desirable and in fact the most natural method of rapidly accomplishing the work.

When the necessity was first realised for drilling all holes, the attempt was naturally made, as had been done in punching, to drill them all before bending the plates into form, by means of multiple

drills adapted for drilling a number of holes in a straight line and in a flat plate. The difficulties were at that time greater, owing to the fact that steel plates could not be had of sufficient length to make a complete ring, and lap joints were general in the longitudinal seams. The result of this attempt was that perfect accuracy in the spacing of the holes in the various plates could not be obtained, because the plates were not true segments of a circle. All plates could not therefore be brought together with the holes quite opposite each other ready for riveting; drifting had still to be resorted to, involving the liability of injuring the plates thereby. The necessity for drilling all holes in position, as it is called, that is, after the plates have been bent and put together in rings, was early felt; and this was met in the first instance by mounting the rings on friction rollers under radial drills, and drilling the rivet holes one at a time: obviously a slow method, yet at the time the best available.

Growth of Drilling.—The present position of the process can best be illustrated by reviewing briefly the several steps which have led up to it.

Multiple Fixed Drills.—The late Mr. Adamson was the first, the author believes, to attempt to apply a number of drills at the same time upon the circular seams; and his method of procedure consisted in using a number of horizontal drills mounted independently on stands which were arranged with spindles in radial lines, the boiler shell being placed vertically in the centre on a turntable which was carried by a long sleeve supported on a central column. These drills were all driven simultaneously, but the advancement and withdrawal of each drill had to be done separately, and the rings to be turned round by hand after one set of holes had been drilled. Bearing in mind that Lancashire boilers vary in diameter say from 4 feet to 9 feet, and that rings are made up of plates varying in width from 3 feet to 6 feet, this was only a partial solution of the problem, so much time being occupied in setting, which plays such an important part in all mechanical operations; and the fact that all the drills had to be started and withdrawn separately either necessitated the

employment of a number of men, or else all the drills had to remain idle, waiting for the work to be turned round, until the last one was withdrawn. Such an arrangement of drills does not permit of more than one drill being got to work on each longitudinal butt seam; and the shell had to be raised for every hole if the butt seams were attempted.

Drilling opposite sides of Suspended Shell.—The second step in the development of this work consisted in the employment of two drilling heads on opposite sides of the shell, which was suspended in the centre and turned round on the hook of the crane, so as to bring the holes into position, as shown in Figs. 1 to 3, Plate 117. This kind of machine has done good work. In addition to the two drilling spindles A on the outside of the shell, there are also two spindles B on the inside, one on each support, which are used for countersinking or taking off the burr after drilling. Each spindle is provided with an automatic feed-motion, and is independently withdrawn by rack and pinion as soon as the hole is finished. This design requires two men, on opposite sides of the shell and out of sight of each other: so that the one controlling the rotary adjustment of the shell in the crane has to wait until he receives a signal, by a tap on the shell, that the second drill is withdrawn. The pitching or setting out of all seams in this machine has obviously to be done by hand; and there are naturally other minor inconveniences, such as the time lost in setting the holes exactly opposite the drills, liability to fracture of drills, &c. The inner spindles were advanced or withdrawn by the lever L on the outside of the shell. The holders H on the inside were also made adjustable by levers on the outside, so that after turning the shell round into position for the next hole it was firmly held during the operation of drilling.

An attempt was also made to drill the shells from the inside, either by drills mounted on a column, or by a machine suspended by ropes, in which the resistance of one drill formed the pressure giving the feed to the opposite drill. The difficulties surrounding either plan are so evident that it is a wonder such an attempt was ever contemplated. With the suspended machine it is clear that, if one

hole was finished before the other, there was no resistance left to put pressure on the second drill for enabling it to finish its hole.

Sliding Drill-Standards.—Later on, concurrently with general improvement in boiler construction, drilling began to be treated much more seriously; and it became fully recognised by the best boiler-makers that the whole work of boiler construction would have to be conducted on the lines of mechanical engineering, and that more skilled labour would have to be employed. An important step was taken in this direction by connecting all the drills so as to advance and withdraw them simultaneously, the shell being on a central table, and turned round by worm gearing, with change-wheels for dividing. Three drills were employed, mounted on standards on radial beds, and were advanced and withdrawn simultaneously by sliding the standards themselves on their radial beds. This machine, which was designed by Mr. Jordan of Manchester, was described in a paper read before this Institution in 1878 (page 571), and is shown in Fig. 4, Plate 118. It was introduced at the time when boiler rings were most frequently made in three laps, and when plates did not exceed 4 feet wide, so that the maximum height at which the drills had to work did not exceed 4 feet above the table. For fairly estimating the relative merits of different machines, it has to be borne in mind that, in order to attain the maximum efficiency in drilling any work, it is necessary to secure as far as possible absolute rigidity both in the machine and in the work. Owing to the fact that boiler rings when put together are so flexible, and can be stiffened only to a limited extent by fixing annular frames within them, it becomes of importance that the utmost rigidity should be provided in the machine itself, inasmuch as the flexibility of the work alone is quite sufficient to cause considerable inconvenience, especially in the breakage of drills when just pointing through the plates. In the machine shown in Fig. 4 the simultaneous advance and withdrawal of the three drills are accomplished by sliding the uprights supporting the drilling saddles along their radial beds, the driving and feeding mechanisms being connected together independently through the centre of the machine under the circular

table. One of the chief objections to this plan consists in the base of each upright having to form a slide on the radial bed, whilst the point of resistance of the drill is so high above the base, thus tending to tilt it on the bed, and thereby diminishing the solidity of the support to the drill. Another objection is the limited number of radial beds, each supporting a single drilling spindle, which can be arranged around the central driving wheels: for on this plan it is necessary to have a separate bed for each spindle, seeing that each spindle must point strictly to the centre of the boiler.

Sliding Drills on Fixed Standards.—In order to overcome the objection to the uprights with sliding base, and yet to retain the simultaneous advance and quick withdrawal of all the drills, the author devised in 1880 a feed mechanism shown in Figs. 5 to 7, Plate 119, in which each spindle is advanced by an automatic feed acting through a rack and pinion, arranged so that by employing adjustable stops A and B a pawl P on the lever L rigidly connected with the rack-pinion can be released at any desired point by the stop A, and a spring S is then allowed to bring the spindle back. In returning, the pawl P strikes the second adjustable stop B, and the spindle is thereby put into action again ready for the next hole. This device on each drilling head allows of the uprights being rigidly bolted to the radial beds, which is a great advantage for the increased height at which the drilling spindles have to work, owing to the increased width of plates amounting now to as much as 7 feet. The three drilling heads are arranged around a circular table in the same manner as those in Fig. 4, so that the pressure of any one spindle is counterbalanced by that of the two others. This construction however had the same defect that one spindle only could be conveniently actuated on the same drilling saddle; for these spindles, when working on the circular seams, must all advance and withdraw along radial lines. The increased stiffness however, secured by bolting the uprights rigidly to the radial bed, was a distinct gain when the drills were in action.

Tall Standard for two tiers of drills.—Several machines have been devised in which the drilling spindles are advanced and withdrawn in the foregoing manner. Some have been arranged with two spindles on one saddle, and two saddles on a single high upright on one side only of the central circular table. This forms a sort of two-storied machine, so that two circular seams can be drilled at the same time; but it entails the great disadvantage of requiring two men at work, one above the other, and waiting for and dependent upon each other before the work can be turned round. Another great disadvantage is the impracticability of supporting the work rigidly enough against the drills at so great a height above the table. The method of disengaging all the drilling spindles by stops, and withdrawing them by balance weights or springs, entailed the defect that the drills when so disengaged might occasionally stick in the holes, and consequently any drill on the opposite side of the shell out of sight caused the workman anxiety to see that it was quite clear before turning the ring round.

Drilling radial holes side by side.—In Figs. 8 and 9, Plate 120, is shown a new method, devised by the author in 1887, of advancing and withdrawing any number of drills simultaneously through precisely the same distance, no matter at what angle their spindles may be set, the rate of advance being at a suitable speed for drilling, while the return of all the drills is almost instantaneous. In Figs. 10 to 12, Plates 121 and 122, are shown a sectional elevation and plan of one of the drilling heads, as arranged for a saddle with two drills pointing truly to the centre of the boiler, and with adjustment for varying their distance apart to suit the different diameters of shells and varying pitches of rivets. The drilling spindle D has at the opposite end to the drill a square-threaded screw cut upon it, and upon this is mounted a circular nut N. If the nut were revolved at the same speed as the spindle, no advance of the drill would be made. If however the number of revolutions of the nut be diminished by differential gearing, the drill can be advanced at any determined speed. On the spindle is mounted also a sleeve S, with sliding key, which latter

acts as driver of the gearing for the nut N when the drill is advancing. The connection between the sleeve and the first driving pinion is so formed by a spring catch C that it will drive the revolving nut when the spindle is running in one direction only. Hence, when the direction of rotation of the drill spindles is reversed, the nuts N remain at rest, and the spindles are withdrawn at a speed due to the full pitch of the screw. In this manner therefore any number of drills can simultaneously be advanced slowly, and withdrawn rapidly; and the whole operation is placed easily under the control of a workman standing in one position, by means of a single lever. This construction of drilling heads was designed specially for boiler-drilling machines, because the feed motion is entirely carried by each head : so that, whether the drills are turned about to any angle, or adjusted in any direction, the motion for advancing and withdrawing them simultaneously remains effective. It is capable of a much wider application, and promises to be useful in multiple-drilling machines generally.

The first boiler-drilling machine made with these new drilling heads is shown in Plate 120, in which two drilling saddles are carried by two uprights on opposite sides of a circular table, on which the rings to be drilled are mounted vertically. When the machine is in action, the uprights are rigidly bolted to the longitudinal bed carrying the table; and vertical slides on the face of each upright allow of the saddles being simultaneously raised and lowered by power, for different heights of rings or when drilling the longitudinal butt seams. Each drilling saddle carries two heads, the spindles of which, as shown in the plan, Plate 122, can be adjusted to any angle by right and left-hand screws, so as to point to the centre of a boiler of any diameter; and the centres can be adjusted apart to varying distances from 2 inches upwards, pitches below 2 inches being drilled alternately. The pitching of the holes in the circular seams in this machine is done mechanically by means of Scott's dividing apparatus, which allows of the circle being divided into any number of equal divisions. The pitching of the holes in the longitudinal butt seams is by means of a vertical pitching staff fixed to the uprights; whilst a pointer, fixed to the sliding saddle, is used to read off the divisions.

Multiple Drilling Machine.—Although the machine just described is best adapted for ordinary work, yet with increased thickness of plates and increased diameter of holes it has become necessary to seek increased rigidity, not only in the supports for the drills, but also in those for the work. With this object the author has recently designed the machine shown in Plates 123 to 126, which has just been constructed for Messrs. Joseph Adamson and Co.'s boiler works at Hyde, where it may now be seen in operation. The multiple drilling heads for the circular seam are here mounted upon a cross slide carried by two uprights, as in a planing machine; the cross slide is raised and lowered by hand or power to suit the varying heights of rings. The drills on the cross slide are five in number, Plate 124, and can be set to varying pitches and angles. The drills for the longitudinal butt seams are six in number, Plate 123, and are arranged upon a vertical column on the opposite side of the circular dividing table. A new feature is here introduced by making the table as an annular ring, with a large hole in the centre, and carrying it on friction rollers only. In the central hole stands a strong upright, sliding on an independent bed below the table, so that it can be advanced or withdrawn by a screw actuated from the outside of the boiler shell, and can be brought up against the inside of the shell opposite to the drilling spindles so as to form a rigid support for the work. It is equally available for supporting the shell when drilling the butt seams, by being set in the opposite direction.

The following are the chief features presented by this machine. First, all the drills can be quickly set to varying pitches, and at the same time made to point strictly to the centre of the boiler, without disturbing the action of the machine. Second, whilst so set all the drills can be advanced or withdrawn simultaneously by the workman standing in one position and actuating a single lever only. Third, independent adjustment of each drill is provided, so that any drill can be advanced or withdrawn separately, to suit the different lengths of drills. Fourth, each drill can be independently stopped from advancing, when not required to drill, or when a tacking bolt or other object interferes. Fifth, the drilling heads for the circular seam are rigidly supported

by the uprights at opposite ends of the cross slide. Sixth, the introduction of an internal support to the shell while being drilled greatly increases the rigidity and therefore the rapid and economical performance of the work.

The driving of the machine is so arranged that a quick speed is provided for taking up the clearance between the drill points and the plate; and this increased speed is continued until the drills have well entered and attained almost the full diameter of hole. When drilling circular seams the man stands upon the platform M, Plates 123 and 124, having in front of him the five spindles, of which he has perfect oversight. On this platform are the levers for starting and reversing the machine, and also for giving the quick speed for entering. After one group of holes has been drilled, the ring can be turned round from the same platform, and the internal support also withdrawn and advanced again for the next group.

The use of multiple drills for boiler shells was formerly much impeded by the necessity in many works of employing numerous tacking bolts for holding the rings together. This was mainly due to imperfections in the bending rolls, which in many instances were not equal to the increasing thickness of plates. On one occasion as many as fifteen tacking bolts were required in the circular seam between two rings, though there was only one plate in each ring. Now however the work for the multiple drill is quite cleared, as two bolts only are usually employed in putting rings together; and in some instances the rings are even put together without any bolts at all, thus leaving the work quite clear for the drills.

Speed of Drills and Rate of Feed.—Another important feature in connection with the drilling of boiler shells has hitherto been the speed of drilling, comprising the two elements—speed of rotation and rate of advance. With twist-drills of the common size of 13-16ths inch diameter, and assuming perfect rigidity both in the machine and in the work, the best speeds are 96 revolutions per minute, and for advance 90 revolutions per inch of traverse or $1\frac{1}{16}$ inch per minute. In boiler-drilling however, so different are

the conditions that these rates are little or no guide whatever. The rings are so flexible that, when a drill with a heavy cut on is pointing through the hole, the spring of the plate is released, and the last portion of the hole is almost punched through, and the drill point often twisted off. To obviate this difficulty, and at the same time to keep up the production of the machine, the number of revolutions per inch of traverse has been steadily increased, and the number of revolutions per minute has also been increased: or in other words, finer feed and higher speed. The latest machine with internal support has not yet been tested, though it is naturally expected to yield increased rapidity of drilling; but with the machine shown in Plate 120, which has been fully tested, the best results are obtained by running the drills at as high a speed as 215 revolutions per minute, and advancing at the rate of $1\frac{7}{16}$ inch per minute in 13-16ths inch holes, four holes being drilled at the same time. With 15-16ths inch holes, the machine is capable of drilling $1\frac{7}{32}$ inch per minute, the drills running at the rate of 185 revolutions per minute.

The length of traverse of each drill when drilling 13-16ths inch holes through two plates of a total thickness of $1\frac{1}{8}$ inch is as follows:—length of drill point and clearance $\frac{3}{8}$ inch, thickness of plates $1\frac{1}{8}$ inch, additional traverse due to flexibility of shell $\frac{1}{8}$ inch; making a total traverse of $1\frac{5}{8}$ inch. The time required for drilling each group of holes is as follows:—to take up clearance and enter drills 10 seconds; remaining traverse of $1\frac{1}{4}$ inch 53 seconds; return of drills through distance of $1\frac{5}{8}$ inch 4 seconds; so that the complete cycle of operations, inclusive of actuating the reversing lever, and turning the shell round for the next group, can be accomplished in 1 minute 20 seconds, and easily in $1\frac{1}{2}$ minute. In general practice a little more clearance is given to the drill points in withdrawing the spindles; but the drills are immediately set forward at the quick speed, and the shell is turned round whilst the drills are taking up the clearance.

Modifications for Special Work.—In Plates 123 to 126 the machine is shown adapted for both circular and longitudinal seams;

but as both seams cannot be drilled simultaneously in the same machine, it is preferable in some workshops to divide the machine into two, so that both operations can be going on simultaneously. Several modifications of these machines are made for smaller works or for special purposes. In the machine shown in Plate 127 two of the new drilling heads are mounted on the top of a stand, and an internal holder is fixed for supporting the rings, which are suspended from the crane as in Plate 117. Another machine for use where lap joints and zigzag holes are substituted for the butt seams is shown in Figs. 20 and 21, Plates 128 and 129. Here again the saddle with two spindles slides upon the face of the upright, when drilling longitudinal seams. The spindles in this case can be set, either one beside the other, or one above the other, or zigzag, always pointing however to the centre of the boiler, and advanced and withdrawn as previously described.

Discussion.

Mr. Dixon exhibited a saddle carrying two of the drilling heads, such as were in actual use, showing the means of adjusting them radially for any pitch desired, and showing also the action of the improved feed-motion described in the paper. The chief feature of this feed-motion was that, if the nuts through which the drilling spindles passed were to revolve at the same speed as the drilling spindles, there would be no advance whatever of the latter. By means however of differential gear the speed of the nuts was diminished sufficiently to advance the drills at the required rate. Immediately that the direction of rotation was reversed for withdrawing the drills, the nuts remained at rest, and the drilling spindles came back at the full pitch of the screw, returning through the full distance of four inches in about six seconds, which was really as fast as could be desired. The peculiar feature of the improved

arrangement of drills and feed-motion was that there was no need for the man working the machine to go round it in order to attend to the several drills separately. No matter how many drilling spindles there were, or at what angles they were placed, they could all be advanced and all be withdrawn by the attendant while standing in one position. There was no need to feel any anxiety about any of the drilling spindles that were out of sight; because it was here quite certain that, when the reversing lever had been pushed over, every drilling spindle must have come back through precisely the same distance, being withdrawn really by a positive motion.

In Figs. 22 and 23, Plates 129 and 130, was shown a special machine now being made by his firm for the Midland Railway, for drilling the shells of locomotive boilers. Some engineers preferred to put locomotive boilers together complete before drilling; and the machine here represented was intended for such work. The shell put together complete beforehand was seen to be carried at opposite ends; and the holes were then drilled in position by the machine. The ends of the shell were carried by concentric chucks, for rapidly fixing and rotating it. One of the chucks was provided with a wormwheel and with Scott's dividing apparatus, for spacing the circular seams. Upon the horizontal longitudinal slide were four drilling saddles, so arranged that all the circular seams were drilled at the same time. Three of the drills were working upon the single-riveted seams; and the fourth was arranged for adjusting rapidly to the zigzag holes of the double-riveted seam at the smoke-box end, so as to drill these through the single plate in the same time. When drilling the longitudinal seams, any pair of these drilling heads could be grouped together on the corresponding ring.

Mr. Joseph Adamson said the origin of drilling the rivet holes in boiler-making had nothing to do with the introduction of steel plates, but dated from the terrible explosion of a locomotive boiler at Messrs. Sharp Stewart and Co.'s works in Manchester in 1858. The late Mr. Daniel Adamson and Mr. William Richardson went together to see the terrible effects of the explosion, and were thereby impressed, like a good many others, with the extreme

(Mr. Joseph Adamson.)
unreliability of the material—iron—then used, and with the highly unsatisfactory way in which at that time boiler-making was done. The first result of the explosion was the arrangement of a system of spacing the rivets in lap joints, so that it should no longer be left in the hands of the foreman boiler-maker to decide how the joints should be made. That was the commencement of the present system of boiler-making. It was found further on that it was all very well to make drawings, but the thing was to get the men to work to them. The only way to obtain good work was to go on to drilling the holes, and otherwise to improve the method of manufacture. In those days even a first-class boiler-shop contained only a pair of rolls, a lever punching-machine, a riveting machine, and perhaps a few fires; the last were not thought to be particularly important. Things had altered since then. The effect of that explosion was to establish the inferiority of the material used. In 1858, thanks to the efforts of Mr. Daniel Adamson, and to the acumen which then as now characterised the firm of Messrs. Platt Brothers, the first steel boiler was made. The material used he understood cost no less than £45 a ton; and it might therefore be taken as certain that boiler-makers using so costly a material were extremely careful in the manufacture, in regard to the way in which it should be handled and dealt with. The first steel plate that he remembered being worked was in a locomotive fire-box, to take the place of a copper plate; that was in 1858. In 1862 the multiple drilling machine with fixed drills was made, which was referred to in page 507 of the paper. Though he had not much to do with the designs, he had in 1863 to look after the men who had the charge of attending to the drills. There were six drills round the central turntable; and the spring or vibration of the boiler shell was so serious that a jobbing smith was kept constantly at work on repairing the drills. There were not many boilers drilled with six heads before the number was reduced to two. These machines he had been credibly informed had met the exigencies of the trade for the last thirty-two years. They happened to be in a rather fortunate position: the original drilling machines and all the various modifications of them in subsequent stages were still in existence.

Only yesterday he had gone to ascertain whether the first two steel boilers that were sold as drilled boilers were still in existence. Messrs. Daniel Adamson and Co. had made steel boilers prior to these, and had drilled the holes; but these were the first boilers which were actually sold as drilled boilers. They had commenced working at a sugar house in London in January 1863, and had been working day and night ever since, except during a period of about four years when the works were closed and changed hands. The present proprietors had reset them lately, and were continuing to work them at 50 lbs. pressure per square inch. The boilers were made of Bessemer steel, a material which was called unreliable; they were constructed for a working pressure of 100 lbs., but the pressure had been reduced to 50 lbs. soon after starting, because of the difficulty experienced at that period in keeping tight the steam-pipe joints through the sugar house. The size of the boilers was 30 feet long and 6½ feet diameter; the shell plates were 5-16ths inch thick double riveted throughout. There was a single flue through, of 3 feet 10 inches diameter, made of 5-16ths inch plates, with Adamson flanged seams at 16-inch centres. Originally the furnace had been 24 feet long, with about ninety 3-inch tubes at the back end, forming Cornish multitubular boilers.

So far as he could say, the drilling machine shown in Plate 117 represented about the period of 1875; Plate 120 represented 1887 or 1888; and Plate 123 represented 1894. The present paper had been prepared with a view to its being read at the recent meeting in Manchester, where the members had been invited to see the latest machine at his own works. The time of changing the work on the machines was looked upon as much more important than an additional sixteenth of an inch per minute in the rate of advance of the drills, because these multiple drills ran round the shell in an hour, or they could drill an ordinary boiler-ring including the butt strap in two hours. But if it took an hour to change, it took a great deal of speed to make any difference; whereas, if by more suitable appliances the changing could be done in half an hour, a considerable increase in the output from the machine would be obtained without the excessive wear and tear inseparable from high cutting speeds. These

(Mr. Joseph Adamson.)
drills had not had much work during the three months since they were started; but up to the present time they had got very well through the little they had done.

Mr. Joseph Whitworth Hulse noticed that the drilling machines dealt with in the paper were applicable more particularly to Lancashire boilers; the drilling of other boiler shells had not been touched upon, such as those of marine boilers, on which drilling had been the practice long anterior to the Lancashire boiler, and also locomotive boilers, for which drilling in position was a comparatively recent innovation. Multiple drilling machines had been made twenty or twenty-five years ago by the late Mr. J. S. Hulse, not only for drilling marine boiler-plates in the flat, but also for drilling the holes after the plates had been bent. After a time the machines for drilling the flat plates were discarded, and those only were used which dealt with the plates after bending, and which of course were modified and strengthened for the purpose. In these the boiler shells were placed horizontally, an arrangement which seemed to possess advantages not confined to marine boilers only, but for all sizes of shells, down to the comparatively diminutive drums of water-tube boilers, such as had now been adopted for torpedo-boat destroyers.

The chief features mentioned in page 513 as presented by the machine there described, in which the shell, or rather a section of the shell, was drilled in a vertical position, were shared also by machines dealing with shells placed horizontally. Moreover in the latter might also be included two additional important features: namely first, that all the circumferential seams might be drilled at the same time; and secondly, that the same drill spindles which dealt with the circumferential seams might be readily grouped to do the longitudinal seams also. With regard to the means adopted for withdrawing the drills quickly, it would appear preferable to avoid reversing the direction of rotation, on account of the liability to snip the drills or injure their cutting edges by the reversal.

With reference to locomotive-boiler drilling, it might be of interest to draw attention to the plural drilling machine recently

constructed by his firm for Messrs. Dübs and Co., Glasgow, from the designs of Mr. Charles M. Davies. The general arrangement, as seen from Plates 131 and 132, was strikingly novel. The chief points kept in view in scheming this machine were, firstly, that the numerous sizes and forms of boilers met with in a locomotive-building establishment had to be provided for; and secondly, that it was desirable, and in many cases imperative, for the boiler shells to be completely erected before drilling, and for the drilling to be completed with the fewest possible re-settings. With respect to the first point, it should be borne in mind that the seams connecting the barrel with the throat-plate and the fire-box shell, and in turn the latter with the flanged back-plate, were sometimes neither at right angles nor parallel to the longitudinal axis or vertical plane of the boiler. The boiler shell, after being tacked together by a few service bolts, and fitted with temporary ends having pivots attached, was placed in bearings upon a trolly, and run endwise into or under the machine, and all the holes in the upper half were drilled. Afterwards the boiler was turned half round, bottom upwards, and the holes in the lower half were drilled, the whole of the drilling being thus completed with only one shifting of the work. The machine had two horizontal slide-beds, placed on opposite sides of the pit in which the trolly ran upon rails. Vertical standards carrying the self-contained countershafting were attached to the ends of each bed. In the beds were racks, by means of which the several radial drilling headstocks were traversed longitudinally by hand or power in either direction for rapid adjustment. The radial drilling headstocks consisted of segmental curved arms, along which the spindle slides were traversed by means of curved racks the arcs of the sliding surfaces being struck from the imaginary centre-line of the boiler, so that when dealing with the barrel the drills always pointed radially to the centre. In order to cope with holes at all the various angles met with in a locomotive boiler, each segmental arm was mounted upon a swivel base, and each drill spindle was provided with a radial adjustment in a vertical plane. Rotary motion was transmitted from the countershafts to the drill spindles by means of endless leather bands and bevil gearing,

(Mr. Joseph Whitworth Hulse.)
tension apparatus being fitted to each radial drilling headstock in order to keep the band tight; and friction clutches were provided for starting and stopping each spindle independently. An independent self-acting feed-motion by screw and differential gear was provided for each spindle; and also a quick traverse in and out. The machine shown in Plates 131 and 132 had six drill spindles; but this number might be varied to meet special requirements. He had been informed by the inventor that with four drills only in operation a large locomotive boiler, having upwards of a thousand rivet-holes of 13-16ths inch diameter, had been drilled in the short time of sixteen hours, including setting.

In Plates 133 to 135 was shown a multiple drilling machine made by his firm for the North Eastern Marine Engineering Co., Wallsend, for drilling the shells of large marine boilers. Here the boiler shell was placed horizontally on a series of rollers in front of the drilling machine, which had four horizontal radial arms carrying drill spindles. When these had drilled round a certain portion of the circumference, the shell was partially revolved upon the rollers by power, so as to present a fresh portion to the drills; and so on till the circle was completed. The usual size of holes drilled was from $1\frac{1}{4}$ to $1\frac{3}{8}$ inch, and sometimes up to $1\frac{5}{8}$ inch diameter. The drill spindles made from 150 to 160 revolutions per minute. The rate of advance or feed was $1\frac{1}{16}$ inch per minute, when the drills were making 150 revolutions per minute. The points of the drills were forged flat, with lips slightly bent to give keen cutting edges; twist drills were unable to stand such heavy work, which was equal to a circumferential cutting speed of about 50 feet per minute, with an advance of 1-140th of an inch for each revolution of the drills.

Mr. Thomas Beeley considered the thanks of engineers were due to the author for introducing a principle in drilling boiler shells which had been called for by the peculiarity and the form of the material that had now to be dealt with. From the very commencement in 1857 when steel boilers began to be made he had himself been associated with the late Mr. Daniel Adamson, and from the outset they began with always drilling the shells; the

manner in which the work was done had been well described by Mr. Joseph Adamson. The principal objection however to the first form of multiple drilling machine, although it did accomplish its object, was that all the plates had to be set out and marked off to begin with, and a correct centre-pop made for each individual rivet-hole, in order to get the drills to start in the proper position. But notwithstanding those precautions to secure regularity of drilling, it would be well understood that, with the shell of the boiler slung from a crane, and with each drill head separate, the shell was not held steady enough in any position, but went on wobbling up and down during the whole of the drilling. Moreover if there was any play in the sleeves of the drills, there would be a considerable movement in the shell of the boiler; and the natural consequence was that there could not be perfect alignment of the rivet-holes, nor perfect regularity in their pitch. The first endeavour after that experience was to obtain some fixed base or abutment to drill against; and the next step was to try to accomplish what had been mentioned by Mr. Hulse, namely to put the shell together beforehand, laying it horizontally between centres, and rotating it with each transverse seam in front of a separate drilling head placed upon a bed running parallel with the boiler shell. But in practice that was found to be too expensive a method; and afterwards the simpler plan was reverted to of setting up a single drilling-head, drilling one hole at a time with a single drill. At the present time no doubt it would be considered rather a slow procedure, where a great number of holes had to be drilled, to have simply one drilling head at work. But there was a curious experience connected with that class of drilling, which was worthy of being recorded, and out of which really had arisen the excellent drilling machines described in the paper. The singular experience was that with some of the multiple machines which cost £300 or £400 no more work could be done than with a single drill. Where the work was set out beforehand and a sufficient resistance was given to the drill point, it would be found that nearly as much work could be got through with a single drill as with four drills under the usual conditions under which boiler shells were drilled.

(Mr. Thomas Beeley.)

He had had one drill fixed upon the head of a Tweddell hydraulic riveting machine of the old-fashioned cast-iron pattern, as solid as anything of the kind could be; the resistance was furnished by the hub, and between the two the boiler shell was simply slung from a crane, as it would be for riveting. With that single drill costing only £50 as many holes per hour could be drilled as with a four-spindle machine that cost £300, owing altogether to the firmer resistance offered to the drill point. When there was any flexibility in the material, the drill as soon as it began to come through was forced through at once, to the detriment both of the drill and of the hole itself. Too great stress therefore could hardly be laid upon the importance of making everything as solid as possible in boiler-drilling machines. Drills for boiler-making he considered were required to be four times as strong as those for drilling cast-iron. In a vertical four-spindle drilling machine made for him by Mr. Hulse for drilling the longitudinal butt-joints of boilers, the drilling was done from the inside of the shell, which lay horizontally upon solid cast-iron bearings, the latter again lying on a firm foundation; the resistance therefore was absolute, and the drill could consequently do its full work, because it had an absolute resistance to work against. When the boiler shell stood vertically on end for drilling, as in the machine shown in Plate 120, it was necessary to depend upon putting an angle-iron ring inside the circumferential seam of the boiler, and fixing it with eight or more screws, in order to get what resistance it could offer for the drills to work against. Notwithstanding that precaution, at least half of the drills were broken. It was indeed astonishing, and would seem scarcely credible if it had not been thoroughly observed, that a machine of that kind with four drills could not get through as much work as could be done with two drill points, when the resistance to the latter was absolutely unyielding.

With regard to the machine shown in Plates 123 to 126, which he had seen in operation at Mr. Joseph Adamson's works, it seemed to him that, if it were divided into two, as suggested in page 516, so that the drilling of both circular and longitudinal seams could be carried on independently, it would offer the best solution of any that had yet

been attempted for drilling boiler-shells, affording a rigid resistance to the drill points, and also giving great facility for drilling the holes and withdrawing the drills. The manufacture of boilers was subject to such severe competition that, if one machine, whatever it might have cost, was not capable of doing the work as cheaply as another, it had to be thrown aside and another got immediately, before any risk could arise of work being taken elsewhere to avoid delay in its execution. Difference of speed was a matter which had also occasioned some perplexity to boiler makers generally, because what served well for cast-iron would not do for steel, as regarded either rate of feed or number of revolutions per minute. In his own works he had tried different speeds of revolution for the drills and also different rates of feed. In different machines he had had no less than seven different speeds of drill and seven different rates of feed. The difference he thought had not been fully recognised in the early days of drilling iron boiler-shells. At that time, as was well known, each ring in the shell of a Lancashire boiler was made in three plates. Therefore the first of the machines for drilling in position was made with three drilling heads, so as to drill simultaneously up each vertical or longitudinal seam, and afterwards to drill the transverse or circumferential seam.

The twist-drill had not proved at all successful for drilling steel boiler-plates. It did well enough in fitting shops and elsewhere for drilling wrought-iron; but with a flexible material like steel, and particularly with plates likely to spring upon the drill just when it was immediately passing through, it was found that the ends of the drills got twisted off; and one went after another far too fast to be tolerated, considering that they cost 6*s.* 6*d.* each to renew. Therefore in the boiler-drilling machines which he was working, and which he should continue to work until he could see his way to abandon them for something better, a peculiar form of drill was used, which might be called a bastard twist-drill, being twisted only at its very extremity, through the last half inch of its length. It was twisted through about the same angle as the ordinary twist-drill; but it did not clear itself like the twist-drill. When drilling vertically downwards against a solid resistance, the twist-drill had the great

(Mr. Thomas Beeley.)
advantage that it cleared its own hole as it went on, and did the highest duty; but in drilling horizontally against a yielding resistance such as already mentioned, the bastard twist-drill was the most economical in use, the hole being cleared by the attendant.

For the first steel boilers made by Mr. Daniel Adamson he remembered that as much as £45 per ton was paid for the material, which was procured from Messrs. Howell of Sheffield. The plates were from $\frac{1}{4}$ to 5-16ths inch thick, and the factor of safety was four, as it had previously been for wrought-iron plates. When subsequently the permanent production of Siemens-Martin steel had been realised, he could not understand how it was that the factor of safety had been raised to five by the boiler insurance companies, notwithstanding that boiler plates of this material were really more reliable than either wrought-iron or Bessemer plates at that time. After the Sheffield plates the next steel plates used for boilers by Mr. Adamson were some made at the Mersey Forge, Liverpool, and at Pontypool, which were supplied at £25 per ton. Then Bessemer plates began to be introduced at the same price, and afterwards came down gradually to £17. Subsequently other steel plates began to be introduced; until now, as was well known, the very best material was found to be the cheapest of any that boiler-makers had ever used. Meanwhile drilling had gone on keeping pace with the improvements in boilers, and with the improvement in the material for making them. Hence in respect of pressures the Lancashire boiler could now almost rank alongside the locomotive. Lancashire boilers were being made of $8\frac{1}{2}$ feet diameter to work at 150 or 160 lbs. pressure per square inch, and some even up to 200 lbs. This was all due jointly to the superior method of manufacture, and to the excellent material which various steel-makers were now able to turn out. Although Bessemer steel had been so well spoken of, and although a considerable number of his own boilers made of that material had now been at work for 26 or 27 years, it did not appear to him to be quite a safe material for such use from what he had observed of its behaviour. Boilers of Bessemer steel erected in France, made with a factor of safety of four, had been re-tested by the French government

after ten years' working, and had failed at only double the working pressure, giving way not simply through the line of the rivets, where they might have been expected to go first, because the strength of the seam was calculated at 72 per cent. of that of the solid plate; but the fracture had run right along the solid plate, and then gone into the seam, and out into the solid plate again. There was no material that he had known of any description which in his own experience was equal to the present Siemens-Martin steel for good service rendered in boilers, and for the facility it afforded to all boiler-makers to produce the best work at the minimum cost.

Mr. E. R. Dolby noticed that the drill was withdrawn by means of a screw on the rear end of the spindle; and he asked what means were taken to prevent over-running in the quick return: whether a clutch or a positive motion was used for giving the reverse rotation by which the drill was drawn back. It appeared as though great attention would be required on the part of the workman to prevent the screw from jamming in the nut.

Mr. Jeremiah Head, Past-President, said it seemed to him that, in boiler-making, as in screw-making which had been the subject of the previous evening's discussion, the time had arrived when all work must be done much more accurately than had formerly been thought necessary. Everything indeed in the entire domain of engineering—whether it were an eighty-ton gun or a watch-screw—must be made in an absolutely perfect manner; and the costly and elaborate character of the machinery which was required for attaining this end seemed to have increased on a vast scale in proportion to the article manufactured, and in comparison with what it used to be. Formerly only a few small tools were available, with which to produce large work; but now elaborate machinery was required for accomplishing what at first sight would appear insignificant details. Boiler-making must be thoroughly good engineering work in all respects, otherwise boilers could not stand the higher pressures which were now required, and upon which the efficiency of the steam-engine was so largely dependent. To make a thoroughly

(Mr. Jeremiah Head.)
good job, everything from beginning to end—from the material and the preliminary processes, up to the finished boiler—must be done in a thoroughly scientific and careful way, with the best skill and appliances. The need seemed to be to take the utmost pains with everything as the work proceeded, beginning with the material itself. As mentioned in the paper (page 514), by the time the boiler was ready for drilling, it ought to hold together without any temporary bolting at all. Owing to the rigid abutment provided inside the boiler shell in the author's latest machine, the drills coming into operation outside found a steady resistance to work against. There was no spring at all, and they therefore went right through, without producing any distortion of the shell itself. This appeared to be the principle, which had now been realised in practice. No doubt the fixing of the rigid internal support, to which previous speakers had referred, was a highly important step in regard to the ultimate character of the work; because if there was a yielding support, so that the stress came upon the plates themselves, they must bend about and become distorted, and not only would the drills be broken, but, what was far worse, the consequence of the pressure and stress put upon the boiler shell would be that, when it came back to its proper shape, the holes would not be absolutely fair. It had been said (page 518) that working boiler-makers were not accustomed to drawings. That was certainly true; and it was therefore necessary to provide the proper appliances for performing the whole of the requisite operations—shearing, planing, bending, drilling, and riveting—so that they could not by any means be done wrong. At some works which he had visited a short time previously in the North of England, where it was felt that they had fallen behind the date in boiler-making, it was estimated that it would cost something like £10,000, simply for additional machinery, before they could begin to make even Lancashire boilers in competition with the works in the Manchester district; and the consideration had arisen whether tubulous boilers were not now coming to the front; and if so, whether all the machinery that would have to be provided for the manufacture of Lancashire boilers would not have then to be altered. This was

one of the contingencies for which boiler manufacturers had nowadays to look out.

The excellent material with which boiler-makers had now to deal had been spoken of by Mr. Beeley (page 526); and also the much inferior material which cost £45 a ton some twenty-five years ago. An American engineer had lately been advocating an alloy of aluminium and copper as the best material for making the underframes of railway carriages and wagons, and had represented that for these and other purposes it would be likely to supersede steel. But it must be remembered that at present such an alloy of aluminium and copper could not be produced under something like two shillings a pound; whereas he had no doubt that steel plates of ordinary sizes for boilers would not be considered cheap at one penny a pound: showing how cheap the highest-class steel now was in comparison with any other material which was likely to come into competition with it. While entertaining some misgivings in regard to Bessemer steel for boilers, Mr. Beeley had expressed the opinion (page 527) that there was nothing like open-hearth steel: having in his mind no doubt the material which was now almost universally used in this country for boilers and for ships, namely open-hearth steel made out of Spanish ore by the acid process. When visiting the United States four years ago, he had found at the Carnegie steel works at Homestead that they were then just putting up a considerable number of Siemens open-hearth acid-lined furnaces for the purpose of making boiler plates and ship plates for the American navy; they had one or two furnaces with basic linings, but the rest were acid. Now however in his recent visit he found that the whole of the acid-lined open-hearth furnaces had been altered to basic. The basic steel so made was being regularly used in the American navy, and subjected to the severest Admiralty tests; he understood there were no rejections whatever, and that nothing else was being used. This was a somewhat different material from that advocated by Mr. Beeley; and he mentioned it merely in order to show that the end had scarcely yet been reached, and that probably for all the purposes above mentioned the day might come when the present fine material would be replaced by

(Mr. Jeremiah Head.)
open-hearth basic steel. This was the material which was now being almost exclusively made in Belgium and in Germany, and apparently also in America; whereas in this country steel-makers were as yet adhering almost entirely to the acid open-hearth process for the production of boiler plates and ship plates.

Mr. Leslie S. Robinson asked whether the author had had any experience in regard to drilling the holes for the tubes in tubulous boilers, and at what speed the work could be done. The paper and discussion had thus far dealt with the drilling of cylindrical boiler shells; and it was a difficult matter to get a good drill to deal quickly with the large number of holes that had to be drilled in tubulous boilers. There were two holes to be drilled for each tube; and they had to be good true holes, because the tube ends had afterwards to be expanded in them.

Mr. Dixon said that the new drilling machine made for Mr. Joseph Adamson had intentionally been arranged in the combined form shown in Plates 123 to 126, so that one setting of the rings was sufficient for both the circular and the longitudinal seams. This seemed to be an advantage in some workshops, depending somewhat on the routine followed in the particular shop; and Mr. Beeley would prefer dividing the machine into two (page 524), which could easily be done. It would be observed that the internal support in the centre of the circular turntable served alternately for both groups of drills; when it had been used for drilling the circular seam it could be shifted across to the opposite side to form a rigid support for drilling the longitudinal seam. In testing the machine on completion, a ring had been drilled which had the manhole cut in, and through the latter it was easy to watch the drill points just coming through the shell; and he had not been able to detect the slightest yielding of the shell under the pressure of the drills. In the ordinary drilling of a boiler shell from the outside, it was well known that the shell yielded considerably; and this was where the difficulty had been met with in boiler drilling. It was a difficulty that had been noticed for years past by many engineers; and it had not been easy to obviate it.

This he had now endeavoured to accomplish by means of the substantial and rigid support inside the shell, because the efficiency of the drills undoubtedly depended on the absolute rigidity both of the drill spindles and of the work. So far as the general combination of the machine was concerned, which was illustrated in Plates 123 to 126, he regretted that no two boiler-makers appeared to like to have their machines in the same form; strangely enough nearly every boiler-drilling machine required special modifications and new drawings, to suit the conditions of different workshops.

The practice of placing boiler shells horizontally on rollers when being drilled had been referred to by Mr. Hulse (page 520), by whom it was considered that machines so arranged shared the chief features mentioned in page 513 as presented by those in which the shells were placed vertically. This however he thought could hardly be the case; for when the shell was placed horizontally it involved the tedious process of setting out all the holes by hand, because the shell with its butt straps on did not describe a true circle when rotated on rollers. Each spindle had also to be set independently for every hole, requiring for this purpose three separate adjustments before its axis could be brought normal to the curvature of the plate; and the correct position was arrived at only by a process of guess and trial: whereas in such a machine as was shown in Plates 123 to 126 the drills were only once adjusted for the whole boiler. After starting to work, no time whatever was lost in setting the drills; and much greater accuracy was attained. When the shell was placed vertically on a dividing table, all the spacing of the holes was done mechanically and with the greatest precision; for a single turn of a handle brought the shell round exactly into position ready for another group of holes, without any marking out whatever. With the comparatively light shells of Lancashire boilers other difficulties occurred, owing to their flexibility; for they got out of truth when lying on their sides, and it was quite impracticable when they were horizontal to resist the pressure of the drills by a rigid internal support. Another consideration of some importance was that, in well equipped works where the rings were bent on vertical rolls, it was highly desirable to avoid the trouble of turning

(Mr. Dixon.)
them on to their sides for drilling, because the next operation of riveting had to be done with the rings again vertical.

Although the paper had dealt only with the drilling of cylindrical boiler shells, the machines had been adapted successfully to the drilling of locomotive boilers also. Machines for this purpose had been made by his firm for Messrs. Sharp, Stewart and Co., Glasgow, and for other locomotive builders. The machine described by Mr. Hulse (page 521) was certainly an elaborate design, and seemed to him to be rather too elaborate to prove effective. The six drill spindles which were mounted on the curved arms or jib cranes he imagined would require at least two men to attend to them; and he noticed that the statistics given had reference to the working of only four drills out of the six on the machine. It must in fact be difficult, if not positively dangerous, for a man on the top of the shell to get about among the forest of drilling spindles and driving gear. In regard also to the setting of the work, it seemed to him that, after drilling round the upper portion of the shell, the whole locomotive boiler would require drawing out altogether from under the machine, in order to be able to turn the fire-box up. This design also presented the disadvantages already mentioned of horizontal shells, as all the marking out had to be done by hand, and a separate drill-spindle had to be adjusted accurately for each hole.

The liability of the drills to snip when reversed (page 520) he had not found to exist, nor could he imagine how it could possibly occur; for the drills were not cutting but were through the holes at the time when they were reversed. Even if reversed while cutting, they instantly withdrew from the face, and did not rub on it as would be the case with a common drill reversed but not withdrawn.

The statistics given as to marine boiler drilling (page 522) appeared, as far as he could judge, to agree fairly with those given in the paper (pages 514–15) for smaller holes of 13-16ths and 15-16ths inch diameter.

The necessity for rigidity had been strongly urged by Mr. Beeley (page 523); and he was himself convinced that there was certainly no point so essential in any drilling machine as that of absolute rigidity.

It was not a question of providing against actual breakage, but the more difficult matter of preventing elasticity and vibration from creeping in, and causing defective work. The use of twist-drills also had been approved by Mr. Beeley (page 525) for work in which absolute rigidity could be obtained; this was the case with the new machine, in which he thought that twist-drills were decidedly an advantage. Having seen in operation the small lip-twist drill which Mr. Beeley used (page 525), he considered it was certainly effective where there was any doubt about the rigidity of the machine. The breakage of drills was really due to the elasticity of the boiler shell, and not to anything else. As soon as the drill began just to point through the plate, it almost punched the last bit of the hole; and in doing so, off went the end of the drill. This he considered was the cause of all the trouble in the breakage of drills. It had been a difficult matter to deal with; but he thought the difficulty was now perfectly met by the rigid support from the inside of the shell.

All the drills were rigidly connected together; and there was a gauge to show the workman the distance they had run through; in fact he could tell when they were through by the machine running more easily, and also by the sound, independently of the gauge; and then he reversed the lever. For the quick return of the drill, there was a frictional arrangement for holding the nut fixed from revolving while the direction of the rotation of the drill was reversed. The distance run back depended simply upon how long the drill was left running reversed; if it was left too long, it would of course run too far back and jam; but there were really several inches to spare. As a matter of fact the drills ought to be stopped at the line marked on an adjustable gauge for that purpose.

Though he had not yet made any special machine for drilling the tube-plates of tubulous boilers, he had made a number of drilling machines which almost covered that work; the nearest he thought was the machine for drilling locomotive tube-plates.

The President had great pleasure in asking the members to pass a vote of thanks to Mr. Dixon for his paper. It was doubtless in the memory of many present that drawings for boilers used to go out of

(The President.)
the office with practically no dimensions marked upon them, except the length and the diameter. No doubt there were some works thirty years ago that were much better; but there were many in which matters went on in this fashion. The foreman boiler-maker really decided the size of the rivets, which nobody knew anything about until they asked him; he also decided the pitch of the rivets, and indeed generally everything except the diameter and the length of the boiler; and he also made a wooden model of the uptake on a scale of an inch to a foot, on which tracing paper was used to measure off the plates to be ordered. It was a great stride from boilers made in that fashion to boilers made with such machines as the author's firm and others were now supplying. Modern boilers were made as steam engines were made, as if they were pieces of machinery, instead of mere pieces of iron more or less inaccurately riveted together. The manufacture of boilers had certainly gone forward as fast as the manufacture of engines; and it would have been impossible for the engines of the present day, if made at all, to be used when made, had it not been that the boiler-makers had supplied boilers of the kind which they were now making, and which were as substantial and as mechanical in construction as any other kinds of machinery.

THIRD REPORT OF THE RESEARCH COMMITTEE ON THE VALUE OF THE STEAM-JACKET.

Mr. HENRY DAVEY, *Chairman.*

Since presenting their Second Report in 1892 (Proceedings page 418) the Committee have carried out several experiments with different engines, and under varying conditions of working, with a view of obtaining further data for this research. The results obtained in these experiments are recorded in this Third Report, together with some results gleaned from other sources.

Up to the present time the endeavours of the Committee have been directed chiefly to obtaining reliable results by carefully conducted experiments with steam engines under ordinary conditions of working; and in order to avoid drawing conclusions from too limited a series of observations, it has been necessary to extend the practical experimental work over a considerable period. It has only been through the kind assistance of those who have been able to place steam engines at the service of the Committee, and to whom their indebtedness is gladly acknowledged, that the experiments have been possible. A great deal of work has been done, and many valuable data obtained, which will be made use of at a future time.

Before concluding their research, the Committee have determined to undertake a series of laboratory experiments, with a specially constructed apparatus, for the purpose of endeavouring to ascertain, approximately at least, the laws which govern steam-cylinder condensation; and it is hoped that the results of such experiments, together with the practical information already obtained, may enable the present research to be brought to a useful issue.

RECORDS OF FIVE EXPERIMENTS (Nos. 57–61) ON THE VALUE OF THE STEAM-JACKET.

No. 57.—Experiment on a Triple-Expansion Engine at the Wapping Pumping Station of the London Hydraulic Power Company, by Mr. Bryan Donkin.

Engine.—The engine on which the experiment was made, Fig. 1, Plate 136, is one of six working at the Wapping pumping station of the London Hydraulic Power Co. for supplying water for power purposes at a pressure of about 750 lbs. per square inch. These engines were fully described and illustrated in "The Engineer," vol. 75, January 1893, page 43. As other tests were being conducted at this station, the Engineers, Messrs. Ellington and Woodall, kindly gave permission for a series of steam-jacket experiments to be carried out by Mr. Bryan Donkin, on behalf of the Steam-Jacket Research Committee of this Institution. The six engines at this station are all of the same type and dimensions, but the trials here recorded were all made upon the same engine and while doing its usual work.

The engine is triple-expansion surface-condensing of the ordinary inverted double-acting marine type, made by the Hydraulic Engineering Co., Chester. The diameters of the cylinders are 15 inches, 22 inches, and 36 inches respectively, by gauges, and the stroke of each 24 inches. There are three plunger water-pumps, each 5 inches in diameter, connected direct to the piston-rods, and having the same stroke. Each of the three cylinders has an ordinary

flat slide-valve actuated by a separate eccentric on the crank-shaft. The high-pressure slide-valve is provided with a variable-expansion valve adjustable by hand, and the low-pressure valve is a double-ported one. The engine is fitted with a Porter governor, which was disconnected during the trials. The air-pump is 11 inches diameter and 16 inches stroke; and the total cooling surface of the condenser is 530 square feet.

Only the bodies of the three cylinders are provided with jackets, the cylinders forming liners in the jackets. The top and bottom ends of the cylinders are not jacketed. Steam was supplied to each of the three jackets by means of a separate pipe from the main steam-pipe; and the pressure in any of the jackets was kept nearly up to that in the boilers, or reduced to any extent by means of steam cocks on the main pipe. A tested Bourdon gauge was placed on each of the three jackets to indicate the steam pressure. The condensed steam was drained from each jacket by a steam-trap. A small air-cock was placed on each jacket to let out any air that might accumulate, but little or none was found to collect during any of the trials. The bodies of the cylinders are covered with non-conducting composition and sheet steel.

The following table shows the extent of the jacketed and unjacketed portions of the inner surfaces of the three cylinders and the two receivers. The surfaces of the cylinders have been calculated as nearly as possible at the point of release in each—90 per cent. of the stroke in the high-pressure and intermediate cylinders, and 95 per cent. in the low-pressure cylinder; and the surfaces of the passages are also included. A portion of the first receiver is heated by the jacket of the high-pressure cylinder, and portions of the second receiver by the jackets of the intermediate and low-pressure cylinders. From this table it will be seen that only about one-third of the internal surfaces exposed to steam at the points of release in all of the cylinders is jacketed. Only about one-seventh of the whole receiver surface is jacketed.

Wapping.

Cylinders and Receivers.			Area of inner surface exposed to steam at Release.		
			Jacketed.	Unjacketed.	Total.
High-pressure cylinder		sq. feet	6·2	10·9	17·1
		per cent.	36·3	63·7	100·0
Intermediate cylinder		sq. feet	9·1	16·3	25·4
		per cent.	35·8	64·2	100·0
Low-pressure cylinder		sq. feet	15·9	31·4	47·3
		per cent.	33·6	66·4	100·0
First receiver	by high-p. jacket	sq. feet	2·9	19·1	22·0
		per cent.	13·2	86·8	100·0
Second receiver	by inter. jacket	sq. feet	4·2	..	..
		per cent.	6·3	..	..
	by low-p. jacket	sq. feet	5·8	..	..
		per cent.	8·6	..	..
	total	sq. feet	10·0	57·0	67·0
		per cent.	14·9	85·1	100·0

The clearance volumes of the cylinders are, high-pressure 12·3 per cent., intermediate 8·0 per cent., and low-pressure 6·3 per cent. of the volumes swept through by their respective pistons. The clearance surfaces are, high-pressure cylinder 11·6 square feet, intermediate 16·4 square feet, and low-pressure 31·5 square feet.

Each end of each cylinder was provided with a separate indicator attached by a short straight pipe. The indicator springs were all carefully tested, and their corrections allowed for in the various calculations.

Details of Experiment.—The experiment consisted of eleven separate trials: three with full pressure of steam in all the jackets, and lasting about nine hours each; one without steam in any of the jackets, and lasting three hours; and seven with different combinations of jackets, each lasting about two hours, the pressures in the intermediate and low-pressure jackets being reduced by means of valves. Care was always taken to run the engine for some time under experimental conditions, so that the walls might acquire their

normal temperature before the trial was started. The three nine-hour trials were each divided into three sections of about three hours each, as a check; and in each case the three sections were found to give practically the same results.

The following table shows the arrangement of jacketing and the jacket-pressures in each of the eleven trials.

Trial Letter.	Number of Jackets in use.	Steam-pressures, lbs. per square inch above atmosphere.			
		Near high-press. valve-chest.	In Jackets.		
			High-press. Jacket.	Inter. Jacket.	Low-press. Jacket.
		lbs.	lbs.	lbs.	lbs.
a	Three	146	142	142	142
b	,,	145	141	141	141
c	,,	120	116	116	116
d	None	121	..	..	..
e	Three	123	119	75	11
f	Two	121	118	75	..
g	,,	119	116	..	9
h	,,	114	..	73	11
i	One	120	118	..	..
j	,,	112	..	73	..
k	,,	119	..	..	9

Feed and Circulating Water.—The feed-water was carefully measured in accurately gauged tanks as it came from the surface-condenser, and before it was pumped into the boiler by the feed-pumps. The surface-condenser was tested for tightness before the trials, and found in perfect order.

The circulating water was measured in large tanks on the roof, and its rise in temperature was noted every five minutes.

The total quantity of supply-water pumped into the mains was also measured in tanks, and its pressure noted from time to time, so that the pump horse-power could be calculated and compared with the indicated horse-power, to ascertain the mechanical efficiency of engines and pumps combined. The consumption of feed-water per

Wapping.

indicated horse-power per hour in the various trials has been taken as the standard of comparison between the values of the different arrangements of jacketing; and the coal consumption has accordingly not been added to the report in detail.

Jacket and Drain-Water.—The discharge from each jacket and the condensed water from the steam-pipe were collected in separate tanks and weighed. As the water from the steam-pipe drain never actually reached the engine, it is not included in the feed-water consumption.

Radiation.—An engine radiation trial was made, to ascertain the quantity of steam condensed per hour in each of the three jackets when the engine was not working. These quantities were found to be as follows:—

Jacket.	Pressure in Jacket, lbs. per sq. in. above atm.	Weight of Steam condensed per hour.	Pressure in Jacket, lbs. per sq. in. above atm.	Weight of Steam condensed per hour.
	lbs. per sq. in.	lbs.	lbs. per sq. in.	lbs.
High-pressure .	122	26·3	122	19·2
Intermediate .	75	24·8	122	19·6
Low-pressure .	10	28·5	122	47·7
Total from all .	graduated pressures	79·6	full pressures	86·5

These quantities represent the jacket-water per hour due to heat uselessly radiated outwards from the various jackets; and the difference between these and the quantities condensed per hour in the jackets during the different trials will approximately represent the heat passing through the cylinder walls to the working steam. These quantities are given in detail in Table 57, pages 548–9.

Pressures &c.—At frequent intervals throughout all the trials readings were taken of the pressure gauges on the boiler and on the three steam-jackets, and of the vacuum gauge and the engine counter. Indicator diagrams were taken, as nearly as possible

simultaneously from each end of each cylinder, every quarter of an hour throughout each trial. The sets of indicator diagrams nearest to the mean for the two trials c and d are shown in Plate 138; and the same sets of diagrams, expanded lengthwise in the ratio of their piston volumes, and combined, are shown in Plate 139. The maximum indicated horse-power for any one trial was 213·5 in trial e, and the minimum was 167·2 in trial j. The engine with its circulating, air, and feed pumps was also indicated when running without load, and gave 26·3 indicated horse-power at a speed of 60 revolutions per minute. The speed of the engine was kept as steady as possible throughout the experiment; but as it was necessary to keep up the pressure in the mains, the same speed could not be maintained during all the trials. The maximum was 64·17, and the minimum 52·74 revolutions per minute.

Priming.—Samples of the steam on its way to the valve-chest, of the condensed steam from the jackets, and of the boiler water, were taken during the experiment; and these were kindly analysed by Mr. Charles J. Wilson, F.I.C., who found that all the condensed steam-samples showed about 0·15 per cent. of priming. The method of testing was fully described in Proceedings 1892, pages 148–150. No correction has been made for this small amount of priming.

Dryness Fraction.—The dryness fraction of the steam in the cylinders—that is, the ratio of the steam present in the cylinders (as shown by the indicator diagrams) to the total steam used in the cylinders—has been calculated for each of the three cylinders at points just before release. The high and intermediate cylinder diagrams were measured at 90 per cent. of the stroke, and the low at 95 per cent.; and the results of the calculations are given in Table 57, pages 548–9, and are also shown graphically in Plate 147.

It will be seen that, with all the jackets in use at the highest steam-pressure, namely 142 lbs. per square inch above atmosphere in trial a, the dryness fraction is greater in the intermediate cylinder than in the high, and also greater in the low than in the intermediate,

Wapping.

showing that the steam became gradually drier as it passed through the three cylinders. The dryness fractions in the three cylinders in this trial were 87·6 per cent. in the high, 88·3 per cent. in the intermediate, and 94·9 per cent. in the low: so that the exhaust steam from the low-pressure cylinder was discharged into the condenser very nearly dry. When no steam was admitted into any of the jackets, trial d, exactly the reverse took place. The dryness fraction decreased from 87·4 per cent. in the high, to 75·7 per cent. in the intermediate, and 64·5 per cent. in the low-pressure cylinder.

Results and Comparisons.—In the following Table the eleven trials are arranged in their order of merit, according to the consumption of feed-water per indicated horse-power per hour; and the steam-pressures in the steam-pipe and jackets are added.

Trial Letter.	Steam-pressures, lbs. per square inch above atmosphere.				Steam used per I.H.P. per hour.
	Near high-press. valve-chest.	In Jackets.			
		High-press. Jacket.	Inter. Jacket.	Low-press. Jacket.	
	lbs.	lbs.	lbs.	lbs.	lbs.
a	146	142	142	142	14·10
b	145	141	141	141	14·59
c	120	116	116	116	15·14
e	123	119	75	11	15·37
g	119	116	..	9	15·95
k	119	..	..	9	16·05
h	114	..	73	11	16·19
f	121	118	75	..	16·65
j	112	..	73	..	16·79
i	120	118	..	..	16·96
d	121	..	..	..	17·17

In comparing these trials it should be remembered that the speeds could not be kept quite the same in all cases, and that the variations of speed have some effect upon the results.

The best results were obtained in the first three trials, a, b, and c, with boiler steam in all the jackets; and in these three, the higher

the steam-pressure, the less was the consumption. In trial c, in which the jacket-pressures were 116 lbs., the saving by jackets was 11·8 per cent. over trial d without jackets in use, both with about the same boiler pressure, taking feed-water per indicated horse-power per hour as the standard of comparison.

In the last seven trials, e to k, with different numbers of jackets in use and different steam-pressures in the various jackets, the pressures in the intermediate and low jackets were so arranged that the temperature in each jacket was about 25° to 30° Fahr. above the temperature of the initial steam in the corresponding cylinder. The best result was obtained in trial e with steam in all the jackets, the saving being 10·5 per cent. as compared with d. The best single-jacket result was obtained in k with the low jacket alone, the saving being 6·5 per cent. as compared with d. The intermediate jacket alone in j gave a saving of 2·2 per cent.; and the high jacket alone in i, a saving of 1·2 per cent. The best pair of jackets were the high and low together in g, in which the saving was 7·1 per cent.; and so long as the low-pressure jacket was one of the pair, it made little difference in the results whether the high or intermediate jacket was working with it. With the intermediate and low jackets together in h, the saving was 5·7 per cent.; and with the high and intermediate jackets together in f, it was 3·0 per cent. The low jacket alone in k had about double the effect of the other two working together in f. The sum of economies due to the high jacket alone in i, the intermediate jacket alone in j, and the low jacket alone in k, agrees within two-thirds per cent. with the economy due to the three jackets working together in e. In Plate 149 are shown graphically the quantities of total feed-water including jacket-water, and of jacket-water alone, per indicated horse-power per hour, for each of the eleven trials.

The ratio of jacket-water to feed-water with all three jackets on at full pressure, trials a, b, and c, varied from 12·06 to 10·11 per cent.; the former, which was obtained in b, was the maximum for the experiment. The minimum was when only the high jacket was in use in i, in which the ratio of jacket-water to feed-water was as low as 1·65 per cent.

Wapping.

Range of Temperature.—In Table 57, pages 550–1, will be found the maximum and minimum temperatures of steam, and the range of temperature in each cylinder for the different trials. These temperatures are those corresponding with the pressures shown by the indicator diagrams. They have been taken from one-third of the total number of diagrams, the errors of springs being allowed for.

Heat passing through Cylinders.—Line 47 of Table 57, pages 550–1, gives the quantities of heat passing through the cylinders per stroke, and line 48 gives the quantities through the jackets. The former is obtained by multiplying the weight of condensed steam from the surface-condenser by the total heat in the boiler steam above the temperature of the air-pump discharge. Similarly the heat supplied to the jackets in line 48 is the product of the weight of steam condensed in each jacket multiplied by the same factor, namely the total heat in the steam above the temperature of the air-pump discharge. In calculating the heat equivalent to the indicated horse-power, line 50, the mechanical equivalent of heat has been taken as 772 foot-lbs. per thermal unit.

Thermal Efficiencies.—Taking the thermal efficiencies given in line 51, Table 57, as a standard of comparison in the different trials, instead of the weight of water per indicated horse-power per hour, the percentages arrived at are higher in favour of the jackets, as will be seen from the following comparison between trial c with steam at 116 lbs. per square inch in the jackets, and trial d without steam in any of the jackets.

Description of Trials.	Steam used per I.H.P. per hour.	Thermal Efficiency.
	Lbs.	Per cent.
Trial c with 116 lbs. steam in jackets .	15·14	14·64
„ d without „ „ „ .	17·17	12·93
Percentage gain with jackets . .	**11·8** p.c.	**13·2** p.c.

All the thermal efficiencies being given in line 51, Table 57, various comparisons can be made for the different changes in the jackets.

Wapping.

Three longer Trials.—For the three longer trials, a, b, and c, a heat balance-sheet has been made; and the following figures of one trial show the percentages of the total heat received from the boilers, and how these were accounted for in the engine, &c.

Heat expended in power . . .	14·7 per cent.
" in circulating water . .	76·2 " "
" in air-pump discharge water .	2·2 " "
" in jacket-water . . .	1·5 " "
Steam-pipe radiation . . .	3·2 " "
Engine radiation	2·4 " "
Deduct over-balance . . .	−0·2 " "
Total . . .	100·0 per cent.

It may be of interest to add, in regard to these three longer trials in which the coal was weighed, that Welsh coal was used, and the result was an evaporation from and at 212° Fahr. of 12·75 lbs. of water per lb. of coal. The thermal efficiency of the boiler was 82 per cent., the pressure of steam being 140 lbs.

Mechanical Efficiency of Pumps.—The mechanical efficiency of the pumps works out to 97·3 per cent. It may be added that the water flowed into the pumps under a head of some 30 feet. It was possible to ascertain this percentage, because all the water was measured in a large tank before being pumped into the mains. This is the ratio of the actual volume of water pumped, to the calculated volume of the pumps.

Mechanical Efficiency of Engine.—This efficiency, or ratio of the horse-power of water pumped to the actual indicated horse-power, was calculated as 83 per cent. for trial c with 116 lbs. steam in all jackets, thus:—

Pump horse-power . . .	149·0 H.P.
Engine alone	26·3 H.P.
Total for pump and engine . .	175·3 H.P.
Total indicated horse-power . .	179·8 H.P.
Difference for increased friction with load on	4·5 H.P.

Wapping.

TABLE 57 (*continued to page* 551).

Experiment on a Triple-Expansion Vertical Surface-Condensing Engine,

with all Jackets in use, or none;

	Description of Trials.	Three Trials with boiler Steam in ALL the Jackets.		
1	Trial Letter	a	b	c
2	Jackets in use	high inter. low	high inter. low	high inter. low
3	Date of Trial . . . March 1892	18th	11th	7th
4	Duration of Trial . . . hours	9·0	8·0	9·0
5	Number of expansions	13·4	14·8	12·0
	Steam-Pressures	Lbs. per square inch		
6	Near high-pressure valve-chest, above atm.	146	145	120
7	In ,, ,, steam-jacket ,, ,,	142	141	116
8	,, intermediate ,, ,, ,, ,,	142	141	116
9	,, low-pressure ,, ,, ,, ,,	142	141	116
10	In condenser absolute	0·72	0·82	0·88
11	Barometric pressure ,,	14·69	14·45	14·64
12	Mean effective pressure, high-p. cylinder .	55·24	52·60	46·39
13	,, ,, ,, inter. ,, .	25·98	24·13	23·64
14	,, ,, ,, low-p. ,, .	8·57	7·73	7·78
15	Mean effective pressure total reduced to low-pressure cylinder	27·65	25·67	24·48
16	Revolutions per minute . . . revs.	60·77	58·82	59·76
17	Piston speed, feet per minute . . feet	243	235	239
18	Indicated horse-power, high-p. cyl. I.H.P.	70·5	64·9	58·2
19	,, ,, inter. ,, I.H.P.	72·1	64·8	64·5
20	,, ,, low-p. ,, I.H.P.	64·0	55·9	57·1
21	,, ,, total . I.H.P.	206·6	185·6	179·8

(*continued from preceding page*) TABLE 57.

at the Wapping Pumping Station of the London Hydraulic Power Co., also with any one Jacket, or any two.

Trial WITHOUT Steam in any Jacket.	Seven Trials with Steam-pressures graduated to the different Jackets.							
	Steam in ALL Jackets.	Three Trials with Steam in TWO Jackets only.			Three Trials with Steam in ONE Jacket only.			
d	e	f	g	h	i	j	k	1
none	high inter. low	high inter.	high low	inter. low	high	inter.	low	2
16th	21st	16th	17th	17th	16th	17th	17th	3
3·0	2·5	2·0	2·0	2·0	2·0	2·0	2·0	4
8·8	9·3	8·8	9·1	9·1	9·0	9·1	9·2	5
		Lbs.	per	square	inch			
121	123	121	119	114	120	112	119	6
..	119	118	116	..	118	..	..	7
..	75	75	..	73	..	73	..	8
..	11	..	9	11	..	..	9	9
0·93	0·82	0·93	0·81	0·76	0·90	0·80	0·78	10
14·55	14·70	14·56	14·65	14·64	14·56	14·63	14·63	11
52·59	48·96	49·17	50·12	46·17	52·43	46·68	49·39	12
30·12	28·76	33·31	27·68	28·42	29·43	30·58	28·38	13
6·21	8·34	6·34	8·00	8·22	6·40	5·93	8·09	14
26·37	27·38	27·11	26·84	26·65	26·28	25·25	27·06	15
52·74	63·42	54·34	61·15	60·58	54·33	53·83	64·17	16
211	254	217	245	242	217	215	257	17
58·2	65·2	56·1	64·3	58·7	59·8	52·7	66·5	18
72·5	83·2	82·6	77·3	78·6	73·0	75·2	83·1	19
40·3	65·1	42·4	60·2	61·2	42·8	39·3	63·8	20
171·0	213·5	181·1	201·8	198·5	175·6	167·2	213·4	21

Wapping.

TABLE 57 (*continued from preceding page*).

Experiment on a Triple-Expansion Vertical Surface-Condensing Engine, with all Jackets in use, or none;

	Description of Trials.	Three Trials with boiler Steam in ALL the Jackets.		
	Trial Letter	a	b	c
	Jackets in use	high inter. low	high inter. low	high inter. low
	Dryness Fraction of steam just before release			
22	In high-pressure cylinder . per cent.	87·6	85·5	85·5
23	,, intermediate ,, . per cent.	88·3	86·9	86·4
24	,, low-pressure ,, . per cent.	94·9	97·8	95·8
	Jacket-Water, lbs. per hour	lbs.	lbs.	lbs.
25	From high-pressure jacket	39·2	76·0	43·5
26	,, intermediate ,, ...	91·2	91·5	84·0
27	,, low-pressure ,, ...	166·7	160·0	147·9
28	Total from all jackets	297·1	327·5	275·4
29	Due to outward radiation (by experiment)	—	—	86·5
30	Due to heat given to cylinder steam (by difference)	—	—	188·9
31	Jacket-Water, total per indicated horse-power per hour lbs.	1·44	1·76	1·53
32	Jacket-Water, total in percentage of total feed-water . . per cent.	10·21	12·06	10·11
33	Feed-Water, total per indicated horse-power per hour lbs.	14·10	14·59	15·14
34	Feed-Water saved per lb. of jacket-water compared with trial d . . . lbs.			1·33
35	Feed-Water, percentage less compared with trial d . . per cent.			**11·8 p.c.**

(*continued from preceding page*) TABLE 57.

at the Wapping Pumping Station of the London Hydraulic Power Co., also with any one Jacket, or any two.

Trial WITHOUT Steam in any Jacket.	Seven Trials with Steam-pressures graduated to the different Jackets.							
	Steam in ALL Jackets.	Three Trials with Steam in TWO Jackets only.			Three Trials with Steam in ONE Jacket only.			
d	e	f	g	h	i	j	k	
none	high inter. low	high inter.	high low	inter. low	high	inter.	low	
87·4	89·3	89·8	89·6	88·6	89·3	88·2	88·6	22
75·7	85·0	84·8	80·9	83·1	76·6	82·5	79·6	23
64·5	85·7	71·1	81·0	82·5	67·7	67·9	79·5	24
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
..	52·4	49·5	49·2	..	49·0	..	..	25
..	85·6	73·5	..	73·5	..	86·5	..	26
..	85·6	..	102·3	98·5	..	..	109·0	27
..	223·6	123·0	151·5	172·0	49·0	86·5	109·0	28
..	79·6	51·1	54·8	53·3	26·3	24·8	28·5	29
..	144·0	71·9	96·7	118·7	22·7	61·7	80·5	30
..	1·05	0·68	0·75	0·87	0·28	0·52	0·51	31
..	6·83	4·08	4·70	5·37	1·65	3·10	3·18	32
17·17	15·37	16·65	15·95	16·19	16·96	16·79	16·05	33
..	1·71	0·76	1·63	1·13	0·75	0·73	2·20	34
(Trial d)	10·5 p.c.	3·0 p.c.	7·1 p.c.	5·7 p.c.	1·2 p.c.	2·2 p.c.	6·5 p.c.	35

Wapping.

TABLE 57 (*continued from preceding page*).

Experiment on a Triple-Expansion Vertical Surface-Condensing Engine, with all Jackets in use, or none;

	Description of Trials.	Three Trials with boiler Steam in ALL the Jackets.		
	Trial Letter	a	b	c
	Jackets in use	high inter. low	high inter. low	high inter. low
36	Maximum Temperature in high-p. cyl. Fahr.	359·2°	359·0°	345·3°
37	Minimum ,, ,, ,, ,, Fahr.	277·2°	272·6°	272·3°
38	Range of ,, ,, ,, ,, Fahr.	82·0°	86·4°	73·0°
39	Maximum Temperature in inter. cyl. Fahr.	288·3°	281·3°	282·3°
40	Minimum ,, ,, ,, ,, Fahr.	203·4°	197·1°	200·3°
41	Range of ,, ,, ,, ,, Fahr.	84·9°	84·2°	82·0°
42	Maximum Temperature in low-p. cyl. Fahr.	209·6°	204·3°	205·9°
43	Minimum ,, ,, ,, ,, Fahr.	125·9°	129·6°	131·3°
44	Range of ,, ,, ,, ,, Fahr.	83·7°	74·7°	74·6°
45	Temperature of condenser vacuum Fahr.	91°	96°	98°
46	,, of air-pump discharge Fahr.	62·5°	63·7°	63·9°
	Heat to Engine per stroke	Th.U.	Th.U.	Th.U.
47	To Cylinders, above air-pump discharge temp.	416·7	391·7	394·8
48	,, Jackets ,, ,, ,, ,,	47·4	53·7	44·4
49	Total to engine ,, ,, ,, ,,	464·1	445·4	439·2
50	Equivalent to I.H.P. given out . . .	72·62	67·44	64·30
51	Thermal Efficiency (line 50÷49) per cent.	15·65	15·14	14·64

(*concluded from page* 546) TABLE 57.

at the Wapping Pumping Station of the London Hydraulic Power Co., also with any one Jacket, or any two.

Trial WITHOUT Steam in any Jacket.	Seven Trials with Steam-pressures graduated to the different Jackets.							
	Steam in ALL Jackets.	Three Trials with Steam in TWO Jackets only.			Three Trials with Steam in ONE Jacket only.			
d none	e high inter. low	f high inter.	g high low	h inter. low	i high	j inter.	k low	
346·8°	346·8°	346·4°	347·1°	343·8°	347·3°	342·2°	346·7°	36
282·0°	281·9°	286·1°	281·5°	283·0°	281·8°	281·8°	282·3°	37
64·8°	64·9°	60·3°	65·6°	60·8°	65·5°	60·4°	64·4°	38
292·4°	293·4°	296·3°	292·5°	293·5°	292·4°	291·3°	296·8°	39
195·5°	205·5°	196·5°	205·3°	205·5°	197·3°	194·4°	206·0°	40
96·9°	87·9°	99·8°	87·2°	88·0°	95·1°	96·9°	90·8°	41
199·4°	210·1°	200·0°	210·1°	210·2°	201·6°	198·3°	211·5°	42
141·1°	132·1°	140·9°	135·7°	132·0°	140·9°	138·3°	138·8°	43
58·3°	78·0°	59·1°	74·4°	78·2°	60·7°	60·0°	72·7°	44
100°	95°	100°	95°	93°	98°	95°	94°	45
66·0°	66·1°	68·2°	69·4°	69·0°	67·5°	68·6°	70·0°	46
Th.U.	Th.U.	Th.U.	Th.U.	Th.U.	Th.U.	Th.U.	Th.U.	
535·8	464·2	511·3	481·0	481·6	518·0	484·4	495·6	47
0	34·0	21·8	23·7	27·3	8·7	15·5	16·3	48
535·8	498·2	533·1	504·7	508·9	526·7	499·9	511·9	49
69·27	71·93	71·22	70·53	70·04	69·05	66·37	71·09	50
12·93	14·44	13·36	13·98	13·77	13·11	13·28	13·89	51

No. 58.—Experiment on two Triple-Expansion Engines at the Lea Bridge Pumping Station of the East London Water Works; by Mr. Henry Davey, Mr. Bryan Donkin, and Professor T. Hudson Beare.

Object of the Experiment.—To ascertain the advantage of the steam-jackets; and to determine, if possible, the relative value of jacketing any one or more of the cylinders. Permission to make the experiment was kindly given by Mr. William B. Bryan, the Engineer to the East London Water Company, who, together with his assistant Mr. Blackburn, and the rest of his staff, rendered every assistance for carrying it out successfully.

Description of Engines.—The engines tested, Fig. 2, Plate 136, were two in number, duplicates of each other. They are of the inverted marine type, made by Messrs. Yates and Thom, of Blackburn, from the designs of Mr. Bryan. The cylinders are 20·03, 33·99, and 57·05 inches diameter respectively, each having a stroke of 48 inches. The piston rods are each 5 inches diameter, and the pump plungers, which form prolongations of the piston rods, are 30 inches diameter, each plunger having a displacement of 122·4 gallons per revolution. The crank shafts are placed under the pumps and revolve in the sequence—high, low, intermediate. All the cylinders are provided with Corliss valves and the Corliss cut-off; the latter however is not under the control of a governor, but is regulated by hand whilst the engine is running. Each engine is provided with its own surface-condenser having 1,053 square feet of cooling surface; and the steam passing through the engine during the trials was measured by the air-pump discharge. The water from the jackets of each cylinder was measured separately. The two engines experimented with are named "North," and "Central," from their positions in the engine-house.

Jacketing.—Each cylinder has a jacket on the body, and one on each of the ends, the body jacket having a steam space of one inch. Drain-pipes were provided, so that the water drained from the jackets

of each cylinder could be measured separately. The pressure in any jacket could be varied by means of reducing valves.

Clothing.—The cylinders and steam pipes are clothed with about $2\frac{1}{2}$ inches of ordinary composition, with the exception of the bottom covers which are not clothed.

Clearance Volumes.—The clearance volumes of the three cylinders are as follows:—

Cylinder.	Clearance Volume.	Percentage of piston Volume.	Equivalent length of Stroke.
	Cubic feet.	Per cent.	Inches.
High-pressure . .	0·2614	3·08	1·48
Intermediate . . .	0·6474	2·60	1·25
Low-pressure . . .	2·044	2·89	1·39

The volumes of the receivers between the cylinders, from the exhaust valve of the one cylinder to the steam valve of the next, are—first receiver 10·28 cubic feet, and second receiver 31·05 cubic feet.

Clearance Surfaces.—The following tables give the areas of the clearance surfaces, both jacketed and unjacketed; and also the jacketed and unjacketed areas of the clearance and cylinder surfaces exposed to steam at release. The areas of the inner surfaces of the two receivers from valve to valve are—first receiver 84·4 square feet, second receiver 158·9 square feet, both wholly unjacketed.

Clearance surface only. Piston at beginning of stroke.		Area of inner surface exposed to steam at Admission.		
		Jacketed.	Unjacketed.	Total.
High-pressure cylinder	sq. feet	3·9	8·4	12·3
	per cent.	31·7	68·3	100·0
Intermediate cylinder	sq. feet	11·2	14·8	26·0
	per cent.	43·1	56·9	100·0
Low-pressure cylinder	sq. feet	26·6	37·6	64·2
	per cent.	41·4	58·6	100·0

Lea Bridge.

Clearance and Cylinder surfaces.		Area of inner surface exposed to steam at Release.		
		Jacketed.	Unjacketed.	Total.
High-pressure cylinder at 95 per cent. of stroke	sq. feet	20·3	13·5	33·8
	per cent.	60·1	39·9	100·0
Intermediate cylinder at 95 per cent. of stroke	sq. feet	38·1	22·1	60·2
	per cent.	63·3	36·7	100·0
Low-pressure cylinder at 90 per cent. of stroke	sq. feet	67·8	49·0	116·8
	per cent.	58·0	42·0	100·0

From these tables it will be seen that in all the cylinders only about two-fifths of the total internal surface exposed to steam at admission was jacketed, while at release the jacketed internal surface was about two-thirds of the total.

Description of Trials.—Thirteen trials were made, lettered **a** to **n** in Table 58 of the results, pages 560–3. The first eleven, **a** to **k**, were made on the 5th, 6th, 7th, and 10th April 1893; the other two were made on the 15th and 17th November of the same year. All the conditions, with the exception of the jacketing, were maintained as far as possible the same throughout all the trials. Neither the coal used nor the feed-water actually pumped into the boilers was measured, the total weight of air-pump discharge water and jacket-water per I.H.P. per hour being taken as the standard of comparison.

Counters and Gauges.—The engine counters and gauges were read at regular intervals of fifteen minutes throughout trials **a** to **k**, and of twenty minutes in **m** and **n**, the various gauges having been previously tested.

Indicating.—An indicator was attached by the usual short pipe-connection at each end of each cylinder. The indicator springs were all carefully tested, and their corrections allowed for. Sets of diagrams were taken at intervals of fifteen and twenty minutes midway between the counter readings, so that 54 diagrams in all were obtained in each of

the first eleven trials, and 72 in each of the last two. The diagrams nearest to the mean for trials a, e, f, and j are given in Plates 140 and 141.

Measurement of Steam used.—The condensers were tested under water pressure both before and after the trials, and were found to be absolutely free from leakage of circulating water. The air-pump discharge was measured in one set of tanks, and the discharge from the jackets in another; the discharge from the jacket of each cylinder was measured separately, except in trial m when all the jacket-water was taken together in one tank. Details of the air-pump and jacket discharges are given in Table 58, pages 562–3. The following table shows the arrangement of jacketing, and the jacket pressures in each of the thirteen trials:—

Trial Letter.	Engine used for Trial.	Number of Cylinders jacketed.	Steam-pressures, lbs. per square inch above atmosphere.			
			In Boiler.	In Jackets.		
				High-press. Jacket.	Inter. Jacket.	Low-press. Jacket.
			lbs.	lbs.	lbs.	lbs.
a	North	Three	116·3	114·9	112·4	113·1
f	Central	Three	117·4	112·7	41·6	9·8
b	North	Two	117·0	116·1	113·9	..
c	North	Two	115·7	114·6	..	112·4
h	Central	Two	117·1	..	113·1	111·3
d	North	One	115·6	113·3	..	..
i	Central	One	117·9	..	113·2	..
g	Central	One	118·3	..	..	112·5
e	North	None	116·4	..	..	..
j	Central	None	117·5	..	..	..
k	Central	{vacuum in all}	111·1	−13·7	−13·7	−13·7
m	Central	Three	118·3	113·0	42·0	29·6
n	Central	None	119·7	..	..	..

Measurement of Radiation and Heat Losses.—An experiment was made by Professor Beare to ascertain the quantity of steam condensed per hour in each set of jackets when the engines were not working,

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the jacket pressures being maintained as nearly as possible the same as during the trials. The following are the results obtained, including those from the " South " engine, a third engine in the same house.

Jackets.	Pressure in Jackets, lbs. per sq. in. above atm.	Weight of Steam condensed per hour.	Pressure in Jackets, lbs. per sq. in. above atm.	Weight of Steam condensed per hour.
	lbs. per sq. in.	lbs.	lbs. per sq. in.	lbs.
	Central Engine.		*Central Engine.*	
High-pressure .	108	34·7	110	35·7
Intermediate .	41	31·8	110	61·0
Low-pressure .	10·5	10·0	110	112·7
Total from all .	graduated pressures	76·5	full pressures	209·4
	North Engine.		*South Engine.*	
High-pressure .	113	47·5	113	41·3
Intermediate .	113	53·2	113	52·5
Low-pressure .	113	102·5	113	118·6
Total from all .	full pressures	203·2	full pressures	212·4

These quantities of jacket-water per hour are due to heat uselessly radiated from the various jackets; and the differences between these and the quantities condensed per hour in the jackets during the different trials should afford an approximation to the quantity of heat passing through the liner walls when the engine is at work.

Leakage Tests.—All the jackets, valves, and pistons of the North and Central engines were tested for leakage after the trials **a–k** had been made. The two surface condensers had been tested previously, and all the joints made tight before the trials took place. The jackets were tested by admitting steam to them at boiler pressure, and opening all the indicator cocks. The test lasted for nine hours, and the leakage was found to be practically nil in all cases. The steam admission valves were tested by shutting both these and the exhaust valves of each cylinder, and opening the indicator cocks. The pressures in the valve-chests were respectively 120, 35, and 5 lbs. per square inch above the atmosphere. The test lasted two hours,

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and the leakage was practically nil. The pistons were tested for tightness by opening the top steam-valves and the bottom indicator cocks, and shutting the bottom steam-valves, all the exhaust valves, and the top indicator cocks. The valve-chest pressures were 120, 35, and 5 lbs. per square inch above the atmosphere, as before; and the test lasted for two hours. The leakage past the pistons per hour was found to be as follows:—

Piston.	Weight of Steam per hour leaking past pistons with engine standing.	
	North Engine.	Central Engine.
	lbs.	lbs.
High-pressure piston . . .	9·1	5·4
Intermediate „ . . .	3·9	0·3
Low-pressure „ . . .	0·7	0·7
Total Leakage lbs. per hour	13·7	6·4

Dryness Fraction.—The dryness fraction of the steam in the cylinder—that is, the ratio of the steam present in the cylinder (as shown by the indicator diagrams) to the total steam used in the cylinder—has been calculated for each of the three cylinders at a point just before release. The high-pressure and intermediate cylinder diagrams were measured at 95 per cent. of the stroke, and the low-pressure at 90 per cent. The results of the calculations are given in Table 58, pages 562–3, and are also shown graphically in Plate 148.

Priming.—Samples were taken during the experiment from the boilers, steam-pipe drains, jacket drains, and surface condensers; and these were kindly analysed by Mr. Charles J. Wilson, F.I.C., with the following results:—

Steam-pipe samples showed 1·9 per cent. of priming.
Jacket-water „ „ 4·0 „ „ „
Condenser „ „ 0·2 „ „ „

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The method employed for this test was fully described in Proceedings 1892, pages 148–150.

Results and Comparisons.—In the following table the thirteen trials are divided into three groups, and are arranged in these groups in their order of merit according to the total consumption of steam per indicated horse-power per hour; the steam pressures in the boilers and jackets are added. The first group contains the two check trials m and n, which were made upon the Central engine, and which both gave a better steam economy than any of the other trials, with the exception of g also made upon the Central engine. The second group consists of the remaining six trials, f, g, h, i, j, and k, made upon the Central engine; and the third group contains the five trials a, b, c, d, and e, made upon the North engine.

Trial Letter.	Steam-pressures, lbs. per square inch above atmosphere.				Steam per I.H.P. per hour.
	In Boiler.	In Jackets.			
		High-press. Jacket.	Inter. Jacket.	Low-press. Jacket.	
	lbs.	lbs.	lbs.	lbs.	lbs.
	Central Engine (check trials).				
m	118·3	113·0	42·0	29·6	12·50
n	119·7	..	..	..	12·99
	Central Engine.				
g	118·3	..	..	112·5	12·89
f	117·4	112·7	41·6	9·8	13·16
h	117·1	..	113·1	111·3	13·19
j	117·5	..	..	..	13·47
i	117·9	..	113·2	..	13·66
k	111·1	−13·7	−13·7	−13·7	13·94
	North Engine.				
b	117·0	116·1	113·9	..	14·16
a	116·3	114·9	112·4	113·1	14·24
d	115·6	113·3	..	..	14·54
c	115·7	114·6	..	112·4	14·59
e	116·4	..	..	..	14·69

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It will be noticed that the Central engine gave considerably better steam economy than the North; and that the two check trials m and n in the first group, which were made at a much later date, are considerably better than the corresponding trials f and j in the second group. In the second group, trial g, with only the low-pressure cylinder jacketed with full-pressure steam, gave a better result than f with graduated steam pressures in all the jackets; and j, without any of the jackets in use, was better than i with the intermediate cylinder jacketed with full-pressure steam. The least economical result of the Central engine was obtained with the jackets coupled to the condenser, trial k. In the five trials made on the North engine in the third group, comparing b with a, and d with c, the steam consumption in both cases seems to show that the addition of the low-pressure jackets in this engine causes a loss in economy, although the differences in consumption are so slight that they may be due to inevitable errors of observation. Considering similarly trials g and j in the second group, the opposite effect appears to be produced upon the Central engine by the low-pressure jacket. The best result in the second group was obtained with the low-pressure cylinder alone jacketed, in trial g; and the addition of the intermediate cylinder jackets seemed to cause a loss of economy, as indicated by a comparison between j and i. The jacket water drained per hour from the intermediate and low-pressure jackets was about twice as much in the North as in the Central engine.

The detailed conditions and results of the thirteen trials are given in Table 58, pages 560–3; and in Plate 150 the quantities of total feed-water including jacket-water, and of jacket-water alone, per indicated horse-power per hour, are shown graphically.

Lea Bridge.

TABLE 58 (*continued to page* 563).

Experiment on
Two Triple-Expansion Vertical Surface-Condensing Engines,
at the Lea Bridge Pumping Station of the East London Water Works,
with Jackets in use on all Cylinders or none, or on any one or any two.

	Grouping of Trials.	Five Trials on North Engine with different jackets in use.				
1	Trial Letter	a	b	c	d	e
2	Jackets in use	high inter. low	high inter.	high low	high	none
3	Date of Trial . 1893	5 Apr.	7 Apr.	6 Apr.	6 Apr.	5 Apr.
4	Duration of Trial . minutes	185·5	179·5	181	181·5	161·5
5	Number of expansions	18·4	15·9	17·2	15·1	13·5
	Steam Pressures		Lbs.	per square inch		
6	In boiler . above atm.	116·3	117·0	115·7	115·6	116·4
7	,, h.-p. valve-chest ,, ,,	115·0	116·2	114·8	113·4	114·6
8	,, inter. ,, ,, ,,	34·6	37·6	34·8	34·5	34·9
9	,, low-p. ,, below ,,	−2·1	−3·8	−2·2	−3·1	−3·3
10	,, condenser . absolute	1·0	1·0	1·0	1·0	1·0
11	Barometric pressure abs.	14·81	14·91	14·83	14·83	14·82
12	In high-p. jacket above atm.	114·9	116·1	114·6	113·3	..
13	,, inter. ,, ,, ,,	112·4	113·9	..	..	..
14	,, low-p. ,, ,, ,,	113·1	..	112·4	..	..
15	Mean eff. press., high-p. cyl.	43·35	46·39	48·03	53·09	50·42
16	,, ,, inter. ,,	19·45	23·31	18·02	20·85	21·76
17	,, ,, low-p. ,,	7·12	5·29	7·11	5·63	5·51
18	Mean effective pressure, total reduced to low-p. cyl.	19·18	19·07	19·22	19·35	19·22
19	Revolutions per minute revs.	20·54	21·45	21·10	21·37	21·72
20	Piston speed, feet per min. feet	164	172	169	171	174
21	Ind. H.P. high-p. cyl. I.H.P.	65·9	73·6	75·0	84·0	81·0
22	,, ,, inter. ,, I.H.P.	86·9	108·8	82·7	97·0	102·9
23	,, ,, low-p. ,, I.H.P.	90·3	70·1	92·6	74·2	73·9
24	,, ,, total I.H.P.	243·1	252·5	250·3	255·2	257·8

(continued from preceding page) TABLE 58.

Experiment on
Two Triple-Expansion Vertical Surface-Condensing Engines,
at the Lea Bridge Pumping Station of the East London Water Works,
with Jackets in use on all Cylinders or none, or on any one or any two.

Six Trials on Central Engine with different jackets in use.						Two Check Trials on Central Engine.		
f	g	h	i	j	k	m	n	1
high inter. low	low	inter. low	inter.	none	vacuum in all	high inter. low	none	2
5 Apr.	7 Apr.	6 Apr.	6 Apr.	5 Apr.	10 Apr.	15 Nov.	17 Nov.	3
190	171	183	184	158	169	240	240	4
18·3	17·2	19·3	17·1	15·2	14·7	19·0	16·0	5
	Lbs.	per	square	inch		Lbs. per	sq. inch	
117·4	118·3	117·1	117·9	117·5	111·1	118·3	119·7	6
114·6	116·0	114·9	114·5	114·6	108·4	115·9	117·0	7
35·0	35·0	34·8	35·0	34·7	34·7	34·9	34·9	8
−3·0	−3·3	−2·5	−3·5	−3·6	−3·8	−3·1	−3·9	9
1·0	1·0	1·0	1·0	1·0	1·0	0·73	0·74	10
14·81	14·91	14·83	14·83	14·82	14·82	14·64	14·31	11
112·7	..	..	..	..	(−13·7)	113·0	..	12
41·6	..	113·1	113·2	..	(−13·7)	42·0	..	13
9·8	112·5	111·3	..	..	(−13·7)	29·6	..	14
46·50	49·09	43·83	48·43	51·21	50·56	44·58	52·21	15
19·32	18·65	18·14	20·76	20·32	20·36	19·39	21·13	16
6·86	6·92	7·70	6·19	6·09	5·93	6·83	5·56	17
19·24	19·38	19·35	19·32	19·39	19·17	19·01	19·27	18
20·24	21·32	20·14	21·36	21·01	22·51	20·05	20·01	19
162	171	161	171	168	180	160	160	20
69·6	77·4	65·3	76·6	79·6	84·2	66·1	77·3	21
85·1	86·5	79·5	96·5	92·9	99·7	84·6	92·0	22
85·7	91·1	95·7	81·6	79·0	82·4	84·5	68·7	23
240·4	255·0	240·5	254·7	251·5	266·3	235·2	238·0	24

Lea Bridge.

TABLE 58 *(continued from preceding page).*

Experiment on

Two Triple-Expansion Vertical Surface-Condensing Engines, at the Lea Bridge Pumping Station of the East London Water Works, with Jackets in use on all Cylinders or none, or on any one or any two.

	Grouping of Trials.	Five Trials on North Engine with different jackets in use.				
	Trial letter	a	b	c	d	e
	Jackets in use . . .	high inter. low	high inter.	high low	high	none
	Dryness Fraction of steam just before release					
25	In high-p. cylinder per cent.	88·9	88·7	86·9	87·5	85·1
26	„ inter. „ per cent.	91·3	88·0	83·3	81·9	78·5
27	„ low-p. „ per cent.	91·7	73·5	86·0	69·3	64·6
	Jacket-Water, lbs. per hour	lbs.	lbs.	lbs.	lbs.	
28	From high-pressure jackets	77·1	27·9	63·9	37·1	..
29	„ intermediate „	183·8	143·8	..	..	..
30	„ low-pressure „	330·0	..	300·0	..	..
31	Total from all jackets	590·9	171·7	363·9	37·1	..
32	Due to outward radiation (by experiment)	203·2	100·7	150·0	[47·5]	..
33	Due to heat given to cyl. steam (by difference)	387·7	71·0	213·9	—	..
34	Jacket-Water, total per I.H.P. per hour lbs.	2·43	0·68	1·45	0·15	..
35	Jacket-Water, total in p.c. of total feed-water p.c.	17·1	4·8	9·9	1·0	..
36	Feed-Water, total per I.H.P. per hour lbs.	14·24	14·16	14·59	14·54	14·69
37	Feed-Water saved per lb. of jacket-water lbs.	0·19	0·78	0·07	1·00	..
38	Feed-Water, percentage less with steam in jackets . .	**3·1 p.c.**	**3·6 p.c.**	**0·68 p.c.**	**1·0 p.c.**	..
39	Feed-Water, percentage less compared with trial e . .					trial e

(*concluded from page* 560) TABLE 58.

Experiment on
Two Triple-Expansion Vertical Surface-Condensing Engines at the Lea Bridge Pumping Station of the East London Water Works, with Jackets in use on all Cylinders or none, or on any one or any two.

Six Trials on Central Engine with different jackets in use.						Two Check Trials on Central Engine.		
f high inter. low	g low	h inter. low	i inter.	j none	k vacuum in all	m high inter. low	n none	
92·0	78·5	83·2	84·0	87·8	90·0	92·7	90·0	25
91·9	72·7	85·0	85·5	82·0	80·5	89·0	82·4	26
88·2	74·4	92·6	76·8	71·9	72·4	89·1	66·2	27
lbs.	lbs.	lbs.	lbs.		lbs.	lbs.		
61·2	..	..	..	..	0	—	..	28
90·5	..	70·7	68·9	..	0	—	..	29
185·4	141·4	163·7	..	..	0	—	..	30
337·1	141·4	234·4	68·9	..	0	345·0	..	31
76·5	112·7	173·7	61·0	..	0	—	..	32
260·6	28·7	60·7	7·9	..	0	—	..	33
1·40	0·56	0·97	0·27	..	0	1·47	..	34
10·6	4·3	7·4	2·0	..	0	11·8	..	35
13·16	12·89	13·19	13·66	13·47	13·94	12·50	12·99	36
0·22	1·04	0·29	—	..	..	0·33	..	37
2·3 p.c.	**4·3 p.c.**	**2·1 p.c.**	—	..	—	**3·8 p.c.**	..	38
				8·3 p.c.			**11·6 p.c.**	39

No. 59.—Experiment on a Three-Cylinder Compound Engine at the Blackfriars Pumping Station of the London Hydraulic Power Company, by Mr. Bryan Donkin.

Engine.—The engine tested, Fig. 3, Plate 137, is one of four at the London Hydraulic Power Co.'s Station at Falcon Wharf, Blackfriars, and is known as engine No. 1. The trials took place by the kind permission of the engineers, Messrs. Ellington and Woodall. The engine was described and illustrated in Mr. Ellington's paper on "The Distribution of Hydraulic Power in London" to the Institution of Civil Engineers, vol. xciv, 1888, page 1, and in "Engineering," vol. 38, 1884, page 99. A similar engine, No. 4 at this station, was tested by Mr. Bryan Donkin and Professor Kennedy in 1887, and a summary of the experiment, which is referred to in "Engineering," vol. 52, 1891, page 375, is given in No. 33 of the Committee's First Report, Proceedings 1889, page 737. The present experiment was made on 18th October 1893 by Mr. Bryan Donkin, who was present throughout the whole of both trials; Mr. Davey was also present part of the time. Mr. G. Cochrane, the Company's Superintendent, gave much valuable assistance both before and during the trials.

The engine is a vertical three-cylinder compound surface-condensing engine of the ordinary double-acting marine type, made by the Hydraulic Engineering Co., Chester. There are three cylinders, one high- and two low-pressure. The high-pressure cylinder is 19·09 inches diameter, and the two low-pressure are each 25·01 inches, all measured from gauges. The stroke of all three is 24 inches. The small cylinder exhausts its steam into the two larger ones. The three steam pistons are connected directly to the plungers of the three main water-pumps, and the forked connecting-rods work a three-throw crank-shaft. The high-pressure cylinder is placed between the two low-pressure, which are designated left and right, as seen from the front of the engine. The cranks are

120° apart, and follow in the order—high-pressure, left low-pressure, right low-pressure. The pump plungers are 4·98 inches diameter, and the piston-rods 3 inches. There are no tail-rods. The steam-valves are all of the flat type. The cut-off in all three cylinders was kept constant, the governor being disconnected during the trials.

The cylinders and jackets are cast separately, the jacket space between the liners and the cylinders being $1\frac{1}{4}$ inch. The metal of the cylinders is 1 inch thick. The three cylinder bodies could be steam-jacketed, and also the two low-pressure top covers. At admission, before the piston moves, only 12·5 per cent. of the total internal surface touched by steam is jacketed in the small cylinder, and only 25·7 per cent. in each of the two large cylinders. Just before release, at 90 per cent. of the stroke these percentages are respectively 51·3 and 56·3 per cent. The steam is supplied to the five jackets by a short pipe, $1\frac{1}{2}$ inch diameter, from the steam-main near, with branches $\frac{1}{2}$ inch diameter to each jacket. The drain pipes from the jackets are also $\frac{1}{2}$ inch diameter. As these steam-supply pipes are rather small, the full boiler-pressure could not be maintained in the jackets, as will be seen from Table 59, page 570. After the trials were over, the speed was reduced to 15 revolutions per minute, at which speed the full steam-pressure was reached in the jackets. Each body-jacket had a separate pressure-gauge fixed on it; and during the experiment was also provided with two pet-cocks, one at the top and one at the bottom. These were often kept slightly open, and occasionally opened fully; but there were no signs of any air or water collecting, and the steam seemed very dry. The water drained from the body jackets passed through separate steam-traps, and the discharge from each was measured in a separate tank. The drain-pipes from the two low-pressure top-cover jackets were connected, and drained into a fourth tank.

The cylinders are clothed externally round their vertical sides with about one inch of non-conducting material and half an inch of wood casing. The three top covers are also clothed with about one inch of non-conducting material; but the bottom covers are left unclothed.

Blackfriars.

The following table gives the volumes and surfaces of the clearances alone; of the cylinders up to 90 per cent. of their stroke plus the clearances; and of the receiver. The extent of the jacketed and unjacketed portions of the inner surfaces is also given. The figures for the cylinders are the means for the two ends. The clearance volume of the high-pressure cylinder is equivalent to 7·23 per cent. of the piston displacement, or 1·74 inches of the stroke. For each low-pressure cylinder, the clearance volume is equivalent to 6·02 per cent. of the piston displacement, or 1·45 inches of the stroke. The actual distance between the pistons and the covers is about 3–8ths inch.

Volumes and Surfaces.		High-pressure cylinder.		Each Low-pressure cylinder.	
Volumes		Cubic feet		Cubic feet	
Clearance and passages		0·284		0·408	
Cylinder at 90 per cent. of stroke		3·534		6·097	
Total steam ,, ,, ,,		3·818		6·505	
Intermediate Receiver		4·56 cubic feet.			
Surfaces		Sq. feet	Per cent.	Sq. feet	Per cent.
Clearance alone	Jacketed	1·3	12·5	3·7	25·7
	Unjacketed	9·1	87·5	10·7	74·3
	Total	10·4	100·0	14·4	100·0
Clearance plus Cylinder at 90 p.c. of stroke	Jacketed	9·8	51·3	14·8	56·3
	Unjacketed	9·3	48·7	11·5	43·7
	Total	19·1	100·0	26·3	100·0
		Square feet		Per cent.	
Intermediate Receiver	Jacketed	6·2		13·3	
	Unjacketed	40·4		86·7	
	Total	46·6		100·0	

The surface condenser contains 530 square feet of cooling surface; it was tested by water pressure both before and after the trials and found absolutely tight. The following three vertical pumps are worked by means of levers from the cross-head of the high-pressure cylinder:—double-acting circulating pump 8 inches diameter, air-pump 11 inches diameter, and feed-pump $2\frac{1}{4}$ inches diameter; all having a 16-inch stroke.

Blackfriars.

Details of Experiment.—Two separate trials were made, each of three hours' duration without any stoppage; the first was made without steam in any of the jackets, and the second with steam in all the five jackets. Two hours' interval was allowed between the trials, to heat up the metal for the jacketed trial. The steam appeared very dry; but a good deal of water was found at the bottom of the high-pressure cylinder, especially during the unjacketed trial. The counter and pressure-gauges were read every ten minutes; and indicator diagrams from each end of each cylinder were taken every fifteen minutes during both trials, each end of each cylinder being provided with a separate indicator attached by a short straight pipe. The two sets of six indicator diagrams nearest to the mean are given in Plate 142.

No account was kept of the coal, or of the feed-water on its way to the boiler: the water from the surface condenser, and the thermal efficiency, being taken as the standards of comparison in the two trials. The water as it came from the air-pump was measured in two special tanks, each of about 70 gallons capacity; and the quantities were obtained by means of a pointer attached to a float. These tanks had been carefully graduated with a ten-gallon standard can; and the two were filled alternately during the trials, the water when recorded being run to waste. The main steam-pipe was drained about ten feet from the high-pressure valve-chest, but this water is excluded from all the results.

The speed of the engine varied somewhat during the experiment, although the mean speeds were almost exactly the same in both trials. The steam pressures were also practically equal in the two trials; but in the jacketed trial the steam was intentionally throttled a little after it passed the pressure-gauge, and just before it reached the valve-chest of the high-pressure cylinder. Thus, although the pressure-gauge on the main steam-pipe showed the same in the two trials, the pressure of the steam entering the valve-chest was a few lbs. per square inch less in the jacketed than in the unjacketed trial. Had the stop-valve been kept full open in the jacketed trial, the engine would have run at about 60 revolutions per minute. The mean water-pressure in the mains and against the pumps was 713 lbs. per

Blackfriars.

square inch in both trials. With the exception of the slight ordinary working irregularities of speed, no difficulties whatever occurred during the progress of the trials.

Results.—The detailed results of the two trials are given in Table 59, pages 570–1. Comparing the trials on the basis of consumption of feed-water per indicated horse-power per hour, including jacket-water, a gain of 5·43 per cent. in favour of the jacketing is shown. One effect of the jacketing was to increase the mean effective pressure in the two low-pressure cylinders.

Thermal Efficiencies.—The thermal efficiencies for the two trials, or the ratio of the heat turned into useful work to the whole heat supplied to the engine, are given in the following table. The temperature of the air-pump discharge was 96° F. without jackets, and 91° F. with jackets; the heat supplied to the engine has been calculated down to these limits both for cylinder and for jacket steam. The percentage increase in thermal efficiency with the jackets in use is rather lower than the percentage gain in steam consumption.

Jackets *With* or *Without* steam	**Without**	**With**
Heat passing through engine per stroke	Th. Units.	Th. Units.
Through cylinders	569·7	511·4
Through jackets	0·0	51·1
Total through engine.	569·7	562·5
Thermal equivalent of I.H.P. per stroke. . .	68·3	71·1
Thermal efficiency of engine	12·0 p.c.	12·6 p.c.
Percentage increase in efficiency with jackets . .	...	5·0 p.c.

Dryness Fraction.—The dryness fraction of the steam in the cylinders—that is, the ratio of the steam present in the cylinders (as shown by the indicator diagrams) to the total steam used in the cylinders—has been calculated at a point just before release, at

90 per cent. of the stroke in each cylinder. In the two low-pressure cylinders the mean result is 67·3 per cent. of the feed-water present as steam just before release *without* steam in the jackets, and 86·0 per cent. *with* steam in the jackets: showing the steam to be much drier with the jackets in use than without, even although such small portions of the cylinders are jacketed.

Engine running light.—The engine was indicated while running light, that is with the air, circulating, and feed pumps working, but with the water to the main pumps shut off. The result of a mean of three sets of diagrams was 23·43 total indicated horse-power at 49·6 revolutions per minute, *without* steam in jackets, or 22·82 indicated horse-power when reduced to a speed of 48·3 revolutions per minute. Steam was then admitted to the jackets, and after an interval of an hour and a half the engine was again indicated, and the mean of three sets of indicator diagrams gave a total indicated horse-power of 22·99 at a speed of 48·3 revolutions per minute *with* steam in jackets. At the increased speed of 58 revolutions per minute the total indicated horse-powers were 27·95 *without*, and 28·45 *with* steam in the jackets. These figures show that with or without steam in the jackets the engine absorbs practically the same amount of power.

Radiation Trial.—A radiation trial lasting $2\frac{1}{2}$ hours was made with the engine at rest, measuring the discharge water from all the jackets with the same steam-pressures in them as during the jacketed trial. The steam condensed amounted to 77·2 lbs. per hour, and is given in Table 59, page 571. This is equivalent to 29·1 per cent. of the measured jacket-water when the engine was working. The temperature of the engine house was about 80° Fahr.

TABLE 59 (*continued on next page*).

Experiment on a
Three-Cylinder Compound Vertical Surface-Condensing Engine,
at the Blackfriars Pumping Station of the London Hydraulic Power Co.,
WITH *and* WITHOUT *Steam in Jackets.*

1	Jackets, *With* or *Without* Steam	**Without**	**With**
2	Duration of Trial . . . . hours	3	3
3	Number of Expansions	6·54	6·54
	Steam Pressures, lbs. per square inch	lbs.	lbs.
4	By engine-room gauge, above atmosphere . .	79·6	79·3
5	In high-pressure cyl. body-jacket, above atmosphere	..	68
6	„ right low-press. cyl. „ „ „	..	69
7	„ left „ „ „ „ „ „	..	73
8	Maximum in high-pressure cylinder absolute	93·0	91·6
9	Minimum „ „ „ „	18·0	22·0
10	Maximum in right low-press. „ „	20·3	24·2
11	„ „ left „ „ „	20·7	24·4
12	Minimum in right „ „ „	2·6	2·3
13	„ „ left „ „ „	2·5	1·9
14	Vacuum in condenser „	1·6	1·6
15	Barometric pressure „	14·87	14·87
	Range of temperature from diagrams		
16	In high-pressure cylinder . . . Fahr.	100°	88°
17	„ right low-pressure „ . . . Fahr.	93°	107°
18	„ left „ „ . . . Fahr.	95°	114°
	Dryness Fraction of steam at release (90 *p. c. of stroke*)		
19	In high-pressure cylinder . . . per cent.	76·7	83·5
20	Mean in two low-pressure cylinders . per cent.	67·3	86·0

(*concluded from preceding page*) TABLE 59.

Experiment on a
Three-Cylinder Compound Vertical Surface-Condensing Engine,
at the Blackfriars Pumping Station of the London Hydraulic Power Co.,
WITH *and* WITHOUT *Steam in Jackets.*

1	Jackets, *With* or *Without* steam		Without	With
	Mean Effective Pressure, lbs. per square inch		lbs.	lbs.
21	In high-pressure cylinder		51·59	44·90
22	„ right low-pressure „		11·45	14·94
23	„ left „ „		12·81	15·42
24	Total reduced to one low-pressure cylinder . .		54·16	56·38
25	Revolutions per minute . . .	revs.	47·83	47·84
26	Piston speed, feet per minute . .	feet	191	191
27	Indicated horse-power, high-pressure cyl.	I.H.P.	84·5	73·6
28	„ „ right low-press. cyl.	I.H.P.	32·4	42·2
29	„ „ left „ „	I.H.P.	36·2	43·6
30	„ „ mean total .	I.H.P.	153·1	159·4
	Jacket-Water, lbs. per hour		lbs.	lbs.
31	From high-pressure body-jacket		..	63·3
32	„ right low-pressure body-jacket . . .		..	91·7
33	„ left „ „ . . .		..	88·3
34	„ both low-pressure top-cover jackets . .		..	21·7
35	Total from all five jackets		..	265·0
36	Due to outward radiation (by special experiment) .		..	77·2
37	Due to heat through cylinder walls (by difference) .		..	187·8
38	Jacket-Water, total per I.H.P. per hour . . .		..	1·66
39	„ „ in percentage of feed-water .		..	9·2 p.c.
	Feed-Water, including jacket-water		lbs.	lbs.
40	„ total per I.H.P. per hour . . .		19·15	18·11
41	„ saved per lb. of jacket-water . .		..	0·63
42	„ percentage less with all jackets in use .		..	**5·43 p.c.**

No. 60.—Experiment on a Compound Engine at the Hampton Pumping Station of the Southwark and Vauxhall Water Works, by Professor T. Hudson Beare.

Object of Experiment.—To ascertain the advantage obtained by the use of the jackets. Permission to make the experiment was kindly given by Mr. J. W. Restler, the Engineer to the Water Company, and every opportunity was afforded for carrying it out successfully. The engine was not in any way prepared for the experiment, and had been running night and day without an overhaul for about eighteen months previously.

Engine.—This experiment was made upon one of two compound vertical surface-condensing engines of the ordinary inverted double-acting marine type, Fig. 4, Plate 137, designed by Mr. Restler, and constructed by Messrs. Richard Moreland and Son, London. The engines were fully described and illustrated in "The Engineer," vol. 64, July 1887, pages 10 to 98. That description however was taken from the original specification, after the preparation of which several important modifications in detail were introduced, notably in connection with the jacketing arrangements. The cylinders are 32 inches and 52$\frac{5}{8}$ inches diameter, each having a stroke of 84 inches. The piston rods are each 6 inches diameter. The engines are provided with ordinary **D** slide-valves, one at each end of each cylinder, each **D** valve having a Meyer expansion valve. The valve-chests are prolonged to the ends of the cylinders, thereby securing short ports and very small clearance volumes. The

main pumps are of the vertical piston type, placed one under each cylinder, and are worked direct from the engine cross-heads by means of vertical rods arranged so as to pass the crank-shaft. Each pump is 19 inches diameter by 7 feet stroke, and works against a head of about 180 feet of water. The air-pump and feed-pump are actuated by a beam from the cross-head of the high-pressure cylinder, and the circulating pump by a similar beam from the low-pressure cross-head. Each engine has a surface condenser, containing 553 tubes 7 feet long and 1 inch outside diameter, having a total cooling surface of 1,040 square feet. The feed-pump is $4\frac{3}{4}$ inches diameter by 27 inches stroke, the air-pump 24 inches diameter by 39 inches stroke, and the circulating pump 13 inches diameter by 39 inches stroke.

Before the feed-water enters the boiler it passes through an economiser, and is raised some 70° or 80° in temperature.

The bodies and ends of both cylinders are jacketed; also the receiver, steam passages, valve-chests, and covers. The cylinders form liners within the body jackets. The jackets are supplied with steam by separate pipes leading from the main steam-pipes. The cylinders and steam pipes are coated externally with 2 inches of Leroy's non-conducting composition and lagged outside with wood.

The following table gives the areas of jacketed and unjacketed clearance surface for each cylinder, that is the total internal surface exposed to steam at admission, before the piston moves; the areas of jacketed and unjacketed surface of each cylinder, inclusive of clearance, exposed to steam at release, are also given. The areas of the jacketed and unjacketed portions of the inner surface of the receiver, calculated from the exhaust valve of the high-pressure cylinder to the admission valve of the low-pressure cylinder, are also added. From this table it will be seen that about 70 per cent. of the internal surface exposed to steam at the points of release in both of the cylinders is jacketed.

Hampton.

Clearance Surface only. Piston at beginning of stroke.			Area of inner surface exposed to steam at Admission.		
			Jacketed.	Unjacketed.	Total.
High-pressure cylinder	including main-valve passage	sq. feet	7·9	23·6	31·5
		per cent.	25·1	74·9	100·0
	excluding main-valve passage	sq. feet	7·9	20·5	28·4
		per cent.	27·8	72·2	100·0
Low-pressure cylinder	including main-valve passage	sq. feet	16·1	48·1	64·2
		per cent.	25·1	74·9	100·0
	excluding main-valve passage	sq. feet	16·1	44·3	60·4
		per cent.	26·7	73·3	100·0

Clearance and Cylinder Surfaces, measured at 95 per cent. of stroke, excluding main-valve passage.		Area of inner surface exposed to steam at Release.		
		Jacketed.	Unjacketed.	Total.
High-pressure cylinder .	sq. feet	61·8	25·2	87·0
	per cent.	71·0	29·0	100·0
Low-pressure cylinder .	sq. feet	104·8	48·6	153·4
	per cent.	68·3	31·7	100·0

Total Internal Surface of Receiver.		Area of whole inner surface continually exposed to steam.		
		Jacketed.	Unjacketed.	Total.
From high-p. exhaust valve to low-p. admission valve	sq. feet	102·0	70·0	172·0
	per cent.	59·3	40·7	100·0

Hampton.

The clearance and release volumes for the two cylinders are as follows :—

Clearance and Release Volumes.	Total volume.	Percentage of piston volume.	Equivalent length of stroke.
High-pressure cylinder.	Cubic feet	Per cent.	Inches
Clearance volume including main-valve passage	1·02	2·66	2·23
Clearance volume excluding main-valve passage	0·86	2·24	1·88
Total Release volume at 95 per cent. of stroke, excluding main-valve passage	37·35	97·24	81·68
Low-pressure cylinder.			
Clearance volume including main-valve passage	2·22	2·11	1·77
Clearance volume excluding main-valve passage	1·94	1·85	1·55
Total Release volume at 95 per cent. of stroke, excluding main-valve passage	101·74	96·85	81·35

The total volume of the intermediate receiver, measuring between the exhaust valve of the high-pressure cylinder and the admission valve of the low-pressure cylinder, is 34·6 cubic feet.

Details of Experiment.—The experiment extended over Thursday, Friday, and Saturday, the 4th, 5th, and 6th January 1894. The first day's trial was made with steam in all the jackets, and lasted for five hours; the second day's trial was made without steam in any of the jackets, and lasted five hours; the third day's trial was made with steam in the jackets of the high-pressure cylinder and receiver only, and lasted three hours.

The air-pump discharge water was measured in tanks. The water from the cylinder and receiver jackets was collected in three separate tanks, and the results are given in detail in Table 60,

Hampton.

page 579. The condenser and all the steam-jackets were carefully tested for tightness before the trials, and found in perfect order. The counter and gauges were read at regular intervals of twenty minutes throughout the trials, the gauges having been tested before the trial and found correct. Neither the coal used nor the feed-water actually pumped into the boilers was measured, the total weight of air-pump discharge water and jacket water per I.H.P. per hour being taken as the standard of comparison.

An indicator was provided for each end of each cylinder, and attached by the usual short pipe connection. The indicator springs were all tested, and the corrections have been allowed for in calculating the mean effective pressures. Diagrams were taken from each end of each cylinder at intervals of twenty minutes throughout the three trials, each set being taken as nearly as possible simultaneously. In this way 60 diagrams in all were obtained in each of the first two trials, and 36 in the third. The sets of diagrams nearest to the mean for the first two trials are given in Plate 143; and the same sets of diagrams, expanded lengthwise in the ratio of their piston volumes, and combined, are shown in Plate 144.

Radiation Trial.—A radiation test, with the engine not working, was made the week after the above trials, with the same pressure in the jackets; it gave the following results:—

Jackets.	Radiation Water.
High-pressure cylinder	122·4 lbs. per hour.
Low-pressure "	300·0 " "
Receiver	24·8 " "
Total Radiation Water . . .	447·2 lbs. per hour.

Dryness Fraction.—The dryness fraction of the steam just before release, for each of the trials, has been worked out from the indicator diagrams, and the results are given in Table 60, page 579.

Results and Comparisons.—The results are tabulated in detail for the three trials in Table 60, pages 578–80. In the first day's trial, with all the jackets in use, there was a saving in feed-water of

Hampton.

10·0 per cent. as compared with the trial on the following day when all the jackets were out of use. In the third day's trial when the high-pressure cylinder and receiver jackets only were in use, the consumption of steam was increased 2·6 per cent. as compared with the trial without jackets.

Hampton.

TABLE 60 (*continued to page* 580).

Experiment on a
Compound Vertical Surface-Condensing Engine,
at the Hampton Pumping Station
of the Southwark and Vauxhall Water Works,
with Jackets in use on all Cylinders or none,
or with the High-Pressure Cylinder and Receiver Jackets only.

1	Day of Trial	Thursday	Friday	Saturday
2	Jackets in use	high low receiver	none	high receiver
3	Date of Trial 1894	4 Jan.	5 Jan.	6 Jan.
4	Duration of Trial . . hours	5	5	3
5	Number of expansions . . .	8·75	8·26	8·06
	Steam Pressures	lbs. per	square	inch
6	In boilers . . above atmosphere	94·7	94·1	94·1
7	„ high-pressure steam-jacket, above atm.	92·9	..	93·1
8	„ low „ „ „ „	91·1	..	..
9	„ intermediate receiver „ „	13·5	12·6	12·9
10	„ condenser . . . absolute	2·3	2·3	2·2
11	Barometric pressure . . „	14·8	14·6	14·5
12	Mean effective pressure, high-p. cylinder	32·16	35·81	36·13
13	„ „ „ low-p. „	10·31	8·19	8·61
14	Mean effective pressure, total reduced to low-p. cyl.	22·07	21·28	21·82
15	Revolutions per minute . . revs.	21·23	21·22	21·20
16	Piston speed, feet per minute . feet	297	297	297
17	Indicated horse-power, high-p. cyl., I.H.P.	228·9	254·7	256·7
18	„ „ low-p. „ I.H.P.	200·6	159·3	167·3
19	„ „ total I.H.P.	429·5	414·0	424·0

(*continued from preceding page*) TABLE 60.

Experiment on a
Compound Vertical Surface-Condensing Engine,
at the Hampton Pumping Station
of the Southwark and Vauxhall Water Works,
with Jackets in use on all Cylinders or none,
or with the High-Pressure Cylinder and Receiver Jackets only.

		Thursday	Friday	Saturday
	Day of Trial	Thursday	Friday	Saturday
	Jackets in use	high low receiver	none	high receiver
	Dryness Fraction of steam			
20	In high-p. cyl. after cut-off . per cent.	79·4	75·7	77·1
21	„ „ „ before release per cent.	92·1	87·6	85·2
22	„ low-p. „ „ „ . per cent.	85·9	69·4	70·7
	Air-pump discharge Water			
23	Per hour . . . . . . lbs.	6,284	7,315	7,312
24	„ I.H.P. per hour . . . lbs.	14·63	17·67	17·25
	Jacket-Water			
25	From high-pressure jackets per hour lbs.	240	..	255
26	„ low „ „ „ „ lbs.	238	..	..
27	„ receiver „ „ „ lbs.	67	..	120
28	Total Jacket-Water „ „ „ lbs.	545	..	375
29	Total per I.H.P. per hour . . lbs.	1·27	..	0·88
30	„ in percent. of total Feed-Water p.c.	8·0	..	4·9
	Feed-Water, including Jacket-Water			
31	Total per hour . . . . . lbs.	6,829	7,315	7,687
32	„ per I.H.P. per hour . . lbs.	15·90	17·67	18·13
33	Saved per lb. of Jacket-Water . lbs.	1·39	..	(−0·52)
34	Percentage *less* Feed-Water, with steam in all of the jackets	**10·0 p.c.**	..	..
35	Percentage *more* Feed-Water, with steam in high and receiver jackets only .	..	..	**2·6 p.c.**

TABLE 60

(*concluded from page* 578).

Experiment on a
Compound Vertical Surface-Condensing Engine,
at the Hampton Pumping Station
of the Southwark and Vauxhall Water Works,
with Jackets in use on all Cylinders or none,
or with the High-Pressure Cylinder and Receiver Jackets only.

	Day of Trial	Thursday	Friday	Saturday
	Jackets in use	high low receiver	none	high receiver
	Absolute Pressures, lbs. per square inch, measured from indicator diagrams	lbs.	per	sq. inch
36	Maximum initial in high-pressure cyl. .	99·2	98·6	98·2
37	At cut-off „ „ „ .	79·4	81·7	81·4
38	„ release „ „ „ .	26·1	28·6	28·0
39	Minimum exhaust „ „ „ .	19·1	20·0	18·4
40	Maximum initial in low-pressure cyl. .	23·3	20·0	20·8
41	At release „ „ „ .	8·0	7·5	7·6
42	Minimum exhaust „ „ „ .	3·5	3·7	3·7
43	Temperature range in high-p. cyl. Fahr.	102°	99°	103°
44	„ „ „ low-p. „ Fahr.	88°	77°	80°
45	Temperature of air-pump discharge Fahr.	98°	101°	101°
		Th. U.	Th. U.	Th. U.
46	Boiler steam, total heat, Th. U. per lb.	1184	1184	1184
47	Air-pump discharge „ Th. U. per lb.	66	69	69
48	Jacket steam, latent heat Th. U. per lb.	879	..	879
	Heat passing through engine	Th. U.	Th. U.	Th. U.
49	Through Cylinders Th. U. per stroke	2758·0	3203·4	3204·4
50	„ Jackets Th. U. per stroke	239·5	..	163·5
51	Total through engine Th. U. per stroke	2997·5	3203·4	3367·9
52	Equivalent of I.H.P. Th. U. per stroke	432·4	417·1	427·5
53	Thermal Efficiency (line 52÷51) p. c.	14·4 p.c.	13·0 p.c.	12·7 p.c.

No. 61.—Experiment on a Compound Engine and Cornish Boiler at the Vauxhall Station of the South Metropolitan Gas Works, by Mr. Bryan Donkin.

Experiment.—This experiment was made in February and March 1894 on a compound horizontal engine and Cornish boiler at the Vauxhall Station of the South Metropolitan Gas Company, by the permission and with the valuable assistance of Mr. C. C. Carpenter, the Engineer in charge of the works. The engine drives a gas exhauster of Beale's latest pattern, capable of passing 200,000 cubic feet of gas per hour at 90 revolutions per minute, with the engine running at 80 revolutions per minute. The exhauster is provided with fast and loose pulleys, and is driven from a countershaft actuated by a belt from the fly-wheel of the engine. In trials c to f the power of the engine was increased by putting on two water-pumps, also driven by a belt.

Engine.—The engine, Fig. 5, Plate 137, is horizontal tandem compound jet-condensing, made by Messrs. Bryan Donkin and Co., and has cylinders 12 and 20 inches diameter and 27 inches stroke. The high-pressure cylinder is fitted with Meyer expansion-valves, adjustable by hand whilst running. In ordinary working a ball governor controls the steam throttle-valve; but this was disconnected during the trials, the steam being regulated by hand with the expansion. The cylinder walls are 7-8ths inch thick, and are clothed with hair-felt and mahogany lagging. The bodies of both cylinders are steam-jacketed, as well as the front cover of the high-pressure and back cover of the low-pressure cylinder. The steam from the boiler enters the low-pressure body-jacket, and after circulating round it passes through the high-pressure body-jacket, and thence to the valve-chest. The vertical cover-jackets receive their steam from the top, and drain into the body-jackets through holes at the bottom.

Vauxhall.

The details of the clearance surfaces are given in the following table, from which it will be seen that 27 per cent. of the total internal surface touched by steam at admission before the piston moves is jacketed, and 65 per cent. of that at release. The actual clearance between the pistons and covers is 3-8ths inch in each case. The engine is fitted with a jet condenser, so that the feed-water could be measured only before being pumped into the boiler.

Clearance Surface only. Piston at beginning of stroke.			Area of inner surface exposed to steam at Admission. Jacketed.	Unjacketed.	Total.
High-pressure cylinder	including main-valve passage	sq. feet	1·5	4·7	6·2
		per cent.	24·2	75·8	100·0
	excluding main-valve passage	sq. feet	1·5	4·1	5·6
		per cent.	26·8	73·2	100·0
Low-pressure cylinder		sq. feet	2·5	6·7	9·2
		per cent.	27·2	72·8	100·0
Clearance and Cylinder Surfaces, measured at 95 per cent. of stroke, excluding main-valve passage.			**Area of inner surface exposed to steam at Release. Jacketed.**	**Unjacketed.**	**Total.**
High-pressure cylinder .		sq. feet	8·0	4·4	12·4
		per cent.	64·5	35·5	100·0
Low-pressure cylinder .		sq. feet	13·1	7·0	20·1
		per cent.	65·2	34·8	100·0
Total Internal Surface of Receiver.			**Area of whole inner surface continually exposed to steam. Jacketed.**	**Unjacketed.**	**Total.**
From high-p. exhaust valve to low-p. admission valve		sq. feet	0	10·2	10·2

The volume of the receiver, from the exhaust valve of the high-pressure to the admission valve of the low-pressure cylinder, is 0·47 cubic feet. And the clearance and release volumes for the two cylinders are as follows :—

Clearance and Release Volumes.	Total volume.	Percentage of piston volume.	Equivalent length of stroke.
High-pressure cylinder.	Cubic feet.	Per cent.	Inches.
Clearance volume including main-valve passage	0·185	10·57	2·85
Clearance volume excluding main-valve passage	0·164	9·37	2·53
Total Release volume at 95 per cent. of stroke, excluding main-valve passage	1·827	104·35	28·17
Low-pressure cylinder.			
Clearance volume . . .	0·235	4·84	1·31
Total Release volume at 95 per cent. of stroke . .	4·846	99·9	26·96

Boiler.—The boiler used and tested, No. 5, is one of a row of six, and is of the Cornish single-flue type, 5 feet 9 inches diameter and 20 feet long, with flue 2 feet 9 inches diameter without cross water-tubes. The grate is 6 feet long, so that the grate area is 16·5 square feet. The total heating surface is 427 square feet, or 25·9 times the grate area. The direction taken by the hot gases is through the flue, returning under bottom, then round the sides of the boiler to the chimney. The mean chimney draft was about 0·3 inch of water throughout all the trials. The boiler and flues were cleaned a few weeks previous to the trials. The steam was taken from the top of a small dome, the pipe being about 130 feet long with twelve bends in it, fairly well covered with non-conducting material. The drop in pressure between the boiler and the engine was 3·4 lbs.

Fuel and Water Measurements.—The fuel used in all the trials was broken gas coke, and was all carefully weighed. The feed-

water was measured through a Schmidt water-meter, the usual feed pipes being disconnected and closed with blank flanges, so that the water passing through the meter could go nowhere but into the boiler being tested. The stop valves on the main steam-pipe were all shut, so that all the steam generated by No. 5 boiler was sent to the engine being tested, any tendency to leak on the part of the valves being counteracted by keeping the steam pressure practically the same in the other boilers. Salt was put into No. 5 boiler on the mornings of trials a, b, c, and d; and samples of water taken from the boiler and steam-pipe drain during these four trials were kindly analysed by Mr. Charles J. Wilson, F.I.C. All the samples collected showed less than 0·05 per cent. of priming; no correction has been made for this in the calculations. The water meter was tested against a standard 100-gallon tank, both before and after the trials; and as the mean correction was only 0·4 per cent. too high, it has also been neglected in the calculations. In the last two trials the air-pump discharge water was measured over a tumbling bay.

Details of Trials.—Six trials, a to f, were made in all, arranged in three pairs with and without jackets, as follows. Five trials were made of eight hours each, and one of nine hours, trial c being prolonged an hour in order to bring the water level up to what it was at the start.

Trial Letter.	Date of Trial.	Jackets *With* or *Without* Steam.	Steam Pressure in boiler above atm.	Cut-off in high-pressure cylinder.	Load on Engine.
	1894.		lbs. per sq. in.	p.c. of stroke.	
a	12 Feb.	Without	About 50 lbs.	About 20 p.c.	Exhauster only.
b	13 Feb.	With			
c	21 Feb.	Without	Do.	About 40 p.c.	Exhauster and Two Pumps.
d	22 Feb.	With			
e	21 Mar.	Without	About 63 lbs.	About 25 p.c.	Do.
f	22 Mar.	With			

Vauxhall.

The first two trials were made with stoking at intervals of three-quarters of an hour, the fires being kept about 9 to 10 inches thick. That plan was altered in the succeeding trials, when the stoking was done by firing with less coke at a time, and about every quarter of an hour, the fires being kept about 5 to 6 inches thick. This method, as will be seen, gave better results.

Indicator diagrams were taken with very short pipes from the front and back ends of each cylinder every twenty minutes by four indicators; the steam pressures, counter, and other observations were also noted three times per hour.

The engine was indicated running empty, that is with the belt off the fly-wheel; and the result showed 4·45 I.H.P. at 80 revolutions per minute, which is equivalent to a mechanical efficiency of 92 per cent. at the full load of 60 I.H.P. The engine was also indicated when driving the countershaft only, all the belts being on loose pulleys, the result being 8·30 I.H.P. at 80 revolutions per minute. A special radiation experiment of four hours' duration was also made with the engine not running, the steam condensed in the jackets and pipe being at the rate of 34·75 lbs. per hour. No special separator was provided on the steam pipe, but a small drain pipe screwed into the bottom of the main gave 4 to 5 lbs. of water per hour. As this was thought too small a quantity for the length of pipe, a special radiation test was made on the steam pipe, when 18·5 lbs. of steam per hour was found to be condensed by radiation from this pipe. This has been deducted from the gross feed-water, to get the net steam consumed by the engine.

Engine Heat Balance-Sheet, Trials e *and* f.—In trials e and f the water from the air-pump discharge was measured by causing it to flow over a tumbling bay 3·005 inches wide, the mean height of water over this bay being 3·256 inches in trial e, and 3·157 inches in f. The method of making this measurement was fully described and illustrated in the Proceedings of the Institution of Civil Engineers, vol. lxvi, page 286, and Plate 8, Figs. 5–7. From these observations the quantity of condensing water has been obtained by deducting the amount of steam passing through the cylinders from

Vauxhall.

the total air-pump discharge water; and from the condensing water and its mean rise in temperature, which was also measured, the saving due to the use of the jackets for the two trials, as determined by the heat rejected per I.H.P. per minute, has been calculated, and an engine heat balance-sheet drawn up. The relative quantities of heat rejected in the condensing water of the air-pump discharge for the two trials were as follows:—

Trial letter	e	f
Jackets, *With* or *Without* steam	**Without**	**With**
Air-pump discharge water per minute . . lbs.	439·0	419·2
Steam passing through cylinders per minute . lbs.	19·6	17·8
Condensing water per minute (by difference) . lbs.	419·4	401·4
Mean rise in temperature . . . . . Fahr.	44·01°	45·56°
Heat rejected in condensing water per I.H.P. per minute . . . Th. U.	333·2	291·0
Percentage less heat rejected with steam in jackets . . . per cent.		12·7

This gives a result almost identical with that obtained from the method of comparison adopted by Mr. Donkin in former trials, in which the heat rejected is taken as being approximately that which would be required to raise the whole of the air-pump discharge water from the temperature of injection to that of the hot-well (Proceedings Inst. C.E., vol. lxx, page 315, and "Engineering," vol. 46, 1888, page 566). This quantity of heat, which is known as "Donkin's coefficient," works out at 348·7 thermal units in trial e without jackets, and 303·8 in f with jackets, or a saving of 12·9 per cent. with steam in jackets.

In the following engine heat balance-sheet all the quantities are reckoned in thermal units per stroke above 32° Fahr.; and the heat lost by radiation from the main steam-pipe is deducted from the gross heat passing from the boiler, to get the net heat supplied to the engine. The percentages given in the table are in terms of the gross heat passing from the boiler.

Vauxhall.

Trial letter	e		f	
Jackets, *With* or *Without* steam .	Without		With	
Heat in Thermal Units per stroke	Th. U.	Per cent.	Th. U.	Per cent.
In steam passing from boiler .	146·8	100·0	151·3	100·0
Lost by steam-pipe radiation .	2·3	1·6	2·3	1·5
Total passing to engine . .	144·5	98·4	149·0	98·5
Turned into work . . .	14·9	10·1	16·8	11·1
Rejected in condensing water .	115·8	78·9	114·5	75·7
,, ,, condensed steam .	8·3	5·6	7·3	4·8
,, ,, jacket water . .	..	..	4·3	2·8
Lost by engine radiation . .	1·0	0·7	0·9	0·6
Unaccounted for (by diff.) . .	4·5	3·1	5·2	3·5
Total passing from engine . .	144·5	98·4	149·0	98·5

Results and Comparisons.—The results and conditions of the six trials are given in detail in Table 61, pages 588–91. It will be observed from lines 50 and 51, page 591, that, with the exception of the high-pressure cylinder in trials c and d, in each of the three pairs of trials the steam at release in both cylinders is much drier in the jacketed than in the corresponding unjacketed trial. In the low-pressure cylinder, trial e, without jackets, the dryness fraction at release is only 72·8 per cent., as compared with 91·2 per cent. in f the corresponding jacketed trial, or an increase of 25·3 per cent.

The sets of indicator diagrams nearest to the mean for trials e and f, with full load and increased boiler-pressure, are shown in Plate 145; and the same sets of diagrams, expanded lengthwise in the ratio of their piston volumes, and combined, are shown in Plate 146.

Vauxhall.

TABLE 61 (*continued to page 591*).—*Experiment on a Compound Horizontal Jet-Condensing Engine and Cornish Boiler, at the Vauxhall Station of the South Metropolitan Gas Works, with different Loads and Boiler-pressures, and* WITH *and* WITHOUT *Steam in Jackets.*

	Conditions of Trials		Light Load; Low Boiler-press.		Heavy Load; Low Boiler-press.		Heavy Load; High Boiler-press.	
1	Trial Letter		a	b	c	d	e	f
2	Jackets, *With* or *Without* Steam		Without	With	Without	With	Without	With
3	Date of Trial	1894	12 Feb.	13 Feb.	21 Feb.	22 Feb.	21 Mar.	22 Mar.
4	Duration of Trial	hours	8	8	9	8	8	8
5	Cut-off in high-pressure cylinder, percentage of stroke	p.c.	20·7	17·3	45·3	38·4	28·5	24·5
6	No. of expansions		8·8	9·9	5·0	5·6	7·1	7·9
	Steam Pressure, lbs. per square inch, absolute		Lbs. per	sq. inch	Lbs. per	sq. inch	Lbs. per	sq. inch
7	In boiler		64·6	65·0	61·2	64·5	76·9	78·6
8	Near high-pressure valve-chest		61·3	61·6	60·9	61·2	73·5	76·2
9	Maximum initial in high-pressure cylinder		54·4	56·5	55·0	58·4	65·8	71·2
10	At release ,, ,, ,,		16·6	14·8	25·9	23·0	21·9	22·2
11	Minimum exhaust ,, ,, ,,		7·0	6·9	10 0	9·7	8 7	9·6
12	Maximum initial in low-pressure cylinder		10·2	11·2	17·1	15·1	13 4	15·3
13	At release ,, ,, ,,		5·6	5·8	8·0	8·1	7·1	8·0
14	Minimum exhaust ,, ,, ,,		2·1	1·7	2·5	1·9	2·5	2·2
15	Vacuum in condenser		0·9	0·8	1·3	1·2	1·6	1·6
16	Barometric pressure		14·6	14·6	14·9	14·8	14·9	14·9

TABLE 61 (*continued on next page*).—*Experiment on a Compound Horizontal Jet-Condensing Engine and Cornish Boiler, at the Vauxhall Station of the South Metropolitan Gas Works, with different Loads and Boiler-pressures, and* WITH *and* WITHOUT *Steam in Jackets.*

	Conditions of Trials		Light Load; Low Boiler-press.		Heavy Load; Low Boiler-press.		Heavy Load; High Boiler-press.	
	Trial Letter Jackets, *With* or *Without* Steam		a Without	b With	c Without	d With	e Without	f With
17	Mean eff. press. in high-pressure cylinder	lbs. per sq. in.	23·13	21·87	26·80	27·87	29·17	30·45
18	,, ,, ,, ,, low-pressure ,,	lbs. per sq. in.	4·654	5·048	6·525	7·929	5·894	7·597
19	,, ,, ,, total reduced to low-p. cyl.	lbs. per sq. in.	13·00	12·94	16·19	17·98	16·42	18·58
20	Revolutions per minute	revs.	78·06	81·15	80·62	79·87	79·67	79·88
21	Piston speed, feet per minute	feet	351	365	363	359	359	359
22	Indicated horse-power, high-pressure cylinder	I.H.P.	27·58	27·11	33·01	34·01	35·51	37·15
23	,, ,, low-pressure ,,	I.H.P.	15·39	17·35	22·28	26·83	19·89	25·70
24	,, ,, mean total	I.H.P.	42·97	44·46	55·29	60·84	55·40	62·85
25	Range of temperature in high-pressure cylinder	Fahr.	109°	113°	94°	99°	112°	113°
26	,, ,, ,, ,, low-pressure ,,	Fahr.	67°	77°	85°	89°	72°	83°
27	Temperature of boiler steam	Fahr.	297·4°	297·8°	297·0°	297·3°	309·1°	310·6°
28	,, ,, feed-water	Fahr.	53·8°	54·7°	46·5°	48·3°	58·7°	56·5°
29	,, ,, injection water	Fahr.	48·2°	45·3°	38·6°	38·2°	55·53°	51·91°
30	,, ,, hot well	Fahr.	90·2°	85·4°	75·5°	75·1°	99·54°	97·47°
31	,, ,, chimney gases	Fahr.	620°	618°	698°	690°	706°	732°

Vauxhall.

TABLE 61 (*continued from preceding page*).—*Experiment on a Compound Horizontal Jet-Condensing Engine and Cornish Boiler, at the Vauxhall Station of the South Metropolitan Gas Works, with different Loads and Boiler-pressures, and* WITH *and* WITHOUT *Steam in Jackets.*

	Conditions of Trials		Light Load; Low Boiler-press.		Heavy Load; Low Boiler-press.		Heavy Load; High Boiler-press.	
	Trial Letter Jackets, *With* or *Without* Steam		a Without	b With	c Without	d With	e Without	f With
32	Moisture in Coke as used	per cent.	8·0	7·1	6·5	5·5	7·0	10·0
33	Calorimetric value of Dry Coke per lb., in lbs. water from and at 212° F.	lbs.	12·77	12·77	12·15	12·15	13·05	13·05
34	Wet Coke used per hour	lbs.	154·0	133·0	172·2	162·5	156·2	162·5
35	Dry " " " "	lbs.	141·7	123·5	149·9	153·6	145·3	146·2
36	" " " per I.H.P. per hour	lbs.	3·30	2·78	2·71	2·52	2·62	2·33
37	" " " per square foot of grate area per hour	lbs.	8·59	7·48	9·08	9·31	8·81	8·86
38	" " percentage left as clinker and ashes	per cent.	14·5	11·7	9·1	10·8	—	11·5
39	Feed-Water per hour	lbs.	962·5	908·5	1,284	1,238	1,194	1,233
40	" per square foot of heating surface per hour,	lbs.	2·25	2·13	3·01	2·90	2·80	2·89
41	" per lb. of dry coke used	lbs.	6·79	7·36	8·57	8·06	8·22	8·43
42	" " " " " from and at 212° F.	lbs.	8·09	8·76	10·27	9·65	9·78	10·05
43	Radiation water from steam-pipes per hour	lbs.	18·5	18·5	18·5	18·5	18·5	18·5
44	Net Steam to engine per hour	lbs.	944·0	890·0	1265·5	1219·5	1175·5	1214·5
45	" " " " per I.H.P. per hour	lbs.	21·97	20·02	22·89	20·05	21·22	19·32
46	Percentage less with steam in jackets	per cent.	..	**8·9 p.c.**	..	**12·4 p.c.**	..	**9·0 p.c.**

TABLE 61 (*concluded from page 588*).—*Experiment on a Compound Horizontal Jet-Condensing Engine and Cornish Boiler, at the Vauxhall Station of the South Metropolitan Gas Works, with different Loads and Boiler-pressures, and* WITH *and* WITHOUT *Steam in Jackets.*

	Conditions of Trials		Light Load; Low Boiler-press.		Heavy Load; Low Boiler-press.		Heavy Load; High Boiler-press.	
	Trial Letter Jackets, *With* or *Without* Steam		a Without	b With	c Without	d With	e Without	f With
47	Jacket-Water per hour	lbs.	..	139·0	..	98·6	..	148·2
48	„ per I.H.P. per hour	lbs.	..	3·13	..	1·62	..	2·36
49	„ in percentage of feed-water	per cent.	..	15·6	..	8·1	..	12·2
	Dryness Fraction of steam at release							
50	In high-pressure cylinder	per cent.	72·4	84·4	84·2	83·6	76·9	85·3
51	In low-pressure „	per cent.	70·7	96·6	76·9	87·6	72·8	91·2
52	Percentage increase in low-pressure cylinder with jackets		..	36·6 p.c.	..	13·9 p.c.	..	25·3 p.c.
53	Heat through cylinders per minute	Th. U.	17,518	13,998	23,790	21,082	21,700	19,728
54	„ „ jackets „ „	Th. U.	..	2,590	..	1,855	..	2,743
55	Total heat passing to engine per minute	Th. U.	17,518	16,588	23,790	22,937	21,700	22,471
56	Heat equivalent to I.H.P. per minute	Th. U.	1,837	1,901	2,364	2,601	2,368	2,687
57	Thermal Efficiency of Boiler (line 42 ÷ line 33)	per cent.	63·4	68·6	84·4	79·4	74·9	77·0
58	„ „ „ Engine (line 56 ÷ line 55)	per cent.	10·48	11·46	9·94	11·34	10·91	11·96
59	„ „ „ Engine and Boiler combined (line 57 × line 58)	per cent.	6·6	7·9	8·4	9·0	8·2	9·2
60	Percentage higher Engine Efficiency with steam in jackets	per cent.	..	9·4 p.c.	..	14·1 p.c.	..	9·6 p.c.

ABSTRACTS OF FOUR EXPERIMENTS, Nos. 62–65, PUBLISHED ELSEWHERE.

No. 62.—*Record of eight Trials on same Engine with different conditions of Jacketing.*

Compound Condensing Horizontal Engine, with Corliss valves placed at the underside of each cylinder. *Cylinders* 25·98 and 45·27 inches diameter, and 53·15 inches stroke. The bodies of both cylinders and the intermediate receiver were jacketed. The cylinder ends were not jacketed. The receiver was tubular, and had its jacket steam all round the tubes. The jackets were supplied with steam by separate pipes, and were provided with air-cocks at their highest points, so that any air accumulating in them could be allowed to escape when desired. Trials made at Loos, near Lille, France, about 1892, by Professor M. A. Witz. (Société Industrielle du Nord de la France, 1892.)

The following table shows the number of jackets in use and the conditions under which each trial was made; and the principal results of the trials are given in Table 62 on next page. The two best results were obtained in trials 3 and 4, with the two cylinder-jackets in use but not the receiver jacket; and trial 7, with steam in the receiver jacket only, gave a higher consumption than trial 8, without steam in any of the jackets.

No. of Trial.	Jackets in use.	Conditions of Trial.
1	High-p., low-p., and receiver	Jacket air-valves kept closed throughout trial.
2	Do.	Air allowed to escape periodically from jackets.
3	High-press. and low-press.	Receiver surrounded by hemp coiling.
4	Do.	Receiver encased and better protected.
5	High-pressure and receiver	Jacket air-valves kept closed throughout trial.
6	Do.	Air allowed to escape periodically from jackets.
7	Receiver alone jacketed	..
8	Without steam in jackets	..

TABLE 62.—*Summary of eight trials on a Compound Horizontal Surface-Condensing Engine, with different conditions of Jacketing, at Loos, near Lille, France, by Professor M. A. Witz.*

No. of Trial.	1	2	3	4	5	6	7	8
Duration of Trial . . hours	12	12	12	12	12	12	12	5·5
Jackets in use (H = high-pressure cyl., L = low-pressure cyl., R = receiver)	H. L. & R.	H. L. & R.	H. & L.	H. & L.	H. & R.	H. & R.	R.	None
Steam Pressures, lbs. per square inch	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
In boiler, above atmosphere . . .	89·2	89·9	89·3	89·2	88·3	89·3	88·2	88·9
Admission in high-p. cyl., above atm. .	85·3	85·9	85·0	85·3	81·3	85·0	84·2	84·9
In condenser, absolute . . .	1·8	2·2	2·3	2·0	1·5	1·9	1·8	1·8
Total mean effective pressure reduced to low-pressure cylinder .	19·25	19·57	20·07	19·71	19·34	19·32	19·59	19·39
Revolutions per minute . . revs.	64·57	64·60	64·39	64·60	64·82	64·93	65·59	65·48
Piston speed, feet per minute, mean, feet	572	572	570	572	574	575	581	580
Indicated Horse-p. in high-p. cyl. I.H.P.	275·1	277·1	313·5	307·4	284·5	293·9	291·9	328·1
,, ,, in low-p. cyl. . I.H.P.	256·2	263·2	239·1	237·7	251·5	242·4	257·1	214·6
,, ,, mean total . I.H.P.	531·3	540·3	552·6	545·1	536·0	536·3	549·0	542·7
Jacket-water per I.H.P. per hour, total, lbs.	1·52	1·70	0·71	0·73	1·39	1·44	1·35	..
,, in p.c. of total feed-water, p.c.	10·5	12·1	5·3	5·3	9·6	10·0	9·1	..
Feed-water per I.H.P. per hour, total lbs.	14·55	14·09	13·56	13·81	14·41	14·41	14·78	**14·63**
,, p.c. less with steam in jackets	**0·5** p.c.	**3·7** p.c.	**7·3** p.c.	**5·6** p.c.	**1·5** p.c.	**1·5** p.c.	**−1·0** p.c.	..

No. 63.—*Record of three Trials on same Engine, WITH and WITHOUT Steam in Jackets.*

Triple-Expansion Condensing Experimental Engine. *Cylinders* 8·99, 16·01, and 24·06 inches diameter, all 30 inches stroke. The bodies and ends of the three cylinders were jacketed, also both receivers. The jackets were supplied with steam by separate pipes, and the water from the several jackets was measured in graduated vessels. Trials made at Massachusetts Institute of Technology from February to May 1892, and reported on by Messrs. C. H. Peabody and E. F. Miller (American Society of Mechanical Engineers, vol. xiv, 1893).

Forty-two trials were made under different conditions of jacketing &c., and are recorded in the paper. The boiler pressure varied from 143·2 to 147·2 lbs. per square inch above the atmosphere, the speed from 83·32 to 93·15 revolutions per minute, the indicated horse-power from 67·45 to 154·2, and the feed-water consumption from 13·74 to 16·25 lbs. per I.H.P. per hour. The three trials summarised below were made with as nearly as possible the same number of expansions. The first of these, No. 17, was made without steam in any of the eleven jackets; the second, No. 4, with steam in the jackets of the three cylinders only, that is in nine jackets, three bodies and six ends; and the third, No. 14, with steam in all eleven jackets. The boilers primed to the extent of 1·1 per cent. throughout the whole of the trials.

Jackets in use	No Jackets	Cylinder Jackets only	All Jackets
Duration of Trial . . . hour	1	1	1
Boiler Pressure, lbs. per sq. in. above atm. lbs.	146·8	146·7	145·5
Number of Expansions	23·8	22·7	23·4
Revolutions per minute . . . revs.	88·95	91·55	92·17
Piston Speed, feet per minute . . feet	445	458	461
Dryness Fraction in cylinder at release: high-p. cyl. per cent.	89·5	94·3	90·7
inter. „ per cent.	85·3	94·6	97·9
low-p. „ per cent.	62·4	92·1	93·8
Results. Indicated Horse-power . I.H.P.	89·3	123·9	125·9
Jacket Water, per I.H.P. per hour . lbs.	..	2·40	2·95
„ „ in p.c. of feed-water . p.c.	..	17·5	20·8
Feed-Water, per I.H.P. per hour . lbs.	15·81	13·74	14·14
„ p.c. less with steam in jackets	..	**13·1 p.c.**	**10·6 p.c.**

No. 64.—*Record of four Trials on same Engine: two with SUPERHEATED steam, WITH and WITHOUT jackets; and two with SATURATED steam, WITH and WITHOUT jackets.*

COMPOUND CONDENSING WOOLF BEAM-ENGINE.—*Cylinders* 20·47 and 35·04 inches diameter, 49·21 and 72·05 inches stroke. Experiments made in 1892 by M. Walther Meunier for the Association Alsacienne des Propriétaires d'Appareils à Vapeur. (Société Industrielle de Mulhouse, vol. lxiii, 1893.)

Two trials with whole steam supply SUPERHEATED.

Jackets, *With* or *Without* Steam	Without	With
Duration of Trial . . . . . .hours	11·70	10·30
Boiler Pressure, lbs. per sq. inch above atm. lbs.	87·6	89·2
Revolutions per minute . . . . . revs.	31·71	31·78
Piston Speed, feet per minute . . . feet	260 & 381	261 & 382
Results. Indicated Horse-power . I.H.P.	255·8	292·0
Feed-Water, lbs. per I.H.P. per hour . lbs.	17·01	15·40
„ percentage less with *superheated* steam in jackets . .	..	**9·5 p.c.**

Two trials with whole steam supply SATURATED.

Jackets, *With* or *Without* Steam	Without	With
Duration of Trial . . . . . .hours	11·88	11·70
Boiler Pressure, lbs. per sq. inch above atm. lbs.	90·2	89·6
Revolutions per minute . . . . . revs.	31·69	31·64
Piston Speed, feet per minute . . . feet	260 & 380	259 & 380
Results. Indicated horse-power . I.H.P.	280·3	287·4
Feed-Water, lbs. per I.H.P. per hour . lbs.	19·85	18·22
„ percentage less with *saturated* steam in jackets . .	..	**8·2 p.c.**

No. 65.—*Record of eight Trials on same Engine, WITH and WITHOUT Steam in Jackets and Receiver-tubes.*

Triple-Expansion Condensing Horizontal Pumping Engine, with Corliss valves, having an arrangement for adjusting the cut-off by hand. *Cylinders* 24·125, 34·0, and 54·0 inches diameter; 35·88, 36·0, and 35·81 inches stroke. All the cylinders were jacketed, the jackets partly covering the cylinder ends. There were two receivers, each containing a nest of reheating tubes, one nest communicating with the intermediate and the other with the low-pressure jacket. The cylinders and reheaters were all protected with non-conducting cement. Experiments made at Laketon, Indiana, U.S.A., in March and April 1893, by Mr. J. E. Denton (American Society of Mechanical Engineers, vol. xiv, 1893). The following table shows the jackets in use, and the percentage of cut-off in the three cylinders for each of the eight trials. The chief results are summarised in Table 65 on next page. The moisture in the steam, as determined by a superheating calorimeter, was found to average 2·5 per cent.

No. of Trial.	Jackets in use.	Cut-off in cylinders. Percentage of stroke.		
		In High-p. cylinder.	In Inter. cylinder.	In Low-p. cylinder.
No.		per cent.	per cent.	per cent.
1	High, Intermediate, and Low .	22·8	40·4	46·8
2	Do. . .	20·9	41·3	46·8
3	Do. . .	23·3	40·1	47·0
4	Do. . .	36·1	39·1	44·3
5	Without steam in jackets . .	31·0	39·6	44·6
6	Intermediate and Low . .	22·6	42·7	52·0
7	High, Intermediate, and Low .	21·5	43·4	53·2
8	Intermediate and Low . .	21·6	42·7	39·4

TABLE 65.—*Summary of eight trials on a Triple-Expansion Horizontal Surface-Condensing Engine, WITH and WITHOUT Steam in Jackets, at Laketon, Indiana, U.S.A., by Mr. J. E. Denton.*

No. of Trial. No.	1	2	3	4	5	6	7	8
Date of trial 1893	31 Mar.	1 Apr.	2 Apr.	4 Apr.	5 Apr.	5 & 6 Apr.	6 Apr.	6 Apr.
Duration of trial . . . hours	6	5	6	8	3	12	5	8
Jackets in use (H=high, I=inter., L=low)	H. I. & L.	H. I. & L.	H. I. & L.	H. I. & L.	None	I. & L.	H. I. & L.	I. & L.
Steam Pressures, lbs. per square inch								
In boiler, above atmosphere . . .	151	151	150	113	151	151	151	152
„ high-p. cylinder jacket, above atm. .	151	151	150	113	..	..	151	..
„ inter. and low-p. cyl. jackets, above atm.	67	135	43	113	..	75	72	62
Total mean effective pressure reduced to low-pressure cylinder . .	27·97	28·20	27·84	27·90	28·59	27·89	27·85	27·00
Revolutions per minute . . . revs.	27·33	27·57	27·65	27·83	27·66	27·94	28·30	28·00
Piston speed, feet per minute, mean feet	163	165	165	166	165	167	169	168
Indicated Horse-power, mean total I.H.P.	317·3	322·8	321·7	322·3	328·1	323·3	327·1	313·7
Pump Horse-power . . . P.H.P.	293·4	298·2	301·3	302·5	299·6	302·7	309·6	297·5
Jacket-Water per I.H.P. per hour, total, lbs.	2·50	2·82	2·08	2·19	..	2·37	2·64	2·43
„ in p.c. of total feed-water, p.c.	18·2	20·4	15·1	15·3	..	17·1	18·9	17·3
Feed-Water per I.H.P. per hour, total, lbs.	13·71	13·84	13·77	14·33	**14·99**	13·84	13·95	14·08
„ p.c. less with steam in jackets	**8·5 p.c.**	**7·7 p.c.**	**8·1 p.c.**	**4·4 p.c.**	..	**7·7 p.c.**	**6·9 p.c.**	**6·1 p.c.**

MEMOIRS.

Thomas Stuart Kennedy was born in 1844 at Feldkirch in the Tyrol, where his father had cotton mills, being one of the first Englishmen who availed themselves of cheap foreign labour and water power. In 1861 he entered as an apprentice the Wellington Foundry of his uncle, the late Sir Peter Fairbairn at Leeds; and on his uncle's death soon afterwards he joined his cousin Sir Andrew Fairbairn and Mr. Naylor in the firm of Fairbairn, Kennedy, and Naylor, by whom the works were thenceforth carried on. On his father's death a few years later he retired from the firm, while yet a young man, and devoted much of his time to outdoor pursuits and field sports, retaining however his interest in mechanics. Being a good mathematician, he strove to introduce the higher mathematics into workshops and drawing office, whereby great economy was effected. He was an excellent worker in metals, and invented several chucks of much utility. Among his many devices was a simple method of taking up wear in the boss of a spherical lathe-rest; and he materially assisted in improving the design of an ornamental lathe. His death which was due to cardiac disease took place at his residence at Wetherby on 17th November 1894, at the age of fifty. He became a Member of this Institution in 1868.

William Henry Prosser was born in Birmingham on 28th October 1843, being the third son of Richard Prosser of Birmingham, who was an engineer and the inventor of several improvements in machinery for welding tubes, of the steam-hydraulic press, and of the dust process for making tiles. He served his apprenticeship to Mr. Walter May at the Suffolk Works, Birmingham, and at the same time was a student at the Midland Institute evening classes. On the termination of his apprenticeship in 1864 he went to London, and entered the service of Messrs. Brown and Harfield. He took a

considerable part in working out the various improvements in ships capstans, windlasses, and steering gear, with which Messrs. Harfields' name has long been associated. From 1886 to 1893 he had charge of the firm's works at Blaydon-on-Tyne; but returned to London in the latter part of 1893 in an enfeebled state of health, and his death took place there on 21st February 1894, at the age of fifty. He became a Member of this Institution in 1874.

Ambrose Shardlow was born at Burton-on-Trent on 5th February 1842. After being educated at Standard Hill Academy, Nottingham, he served his apprenticeship with Messrs. J. Oakes and Co., at the Alfreton Iron Works, Somercotes. He was next employed in the Midland Railway locomotive department at Derby; and afterwards in the engineering works of Messrs. Fletcher and Co., Derby. In 1867 he entered the service of Messrs. Manlove and Co. of Nottingham, who entrusted him with important work in various parts of the country, whereby he gained a wide experience which afterwards proved of much value. In 1870 he commenced business as an engineer in Sheffield, where he soon gained a name for quality of work. His chief invention was a file-cutting machine, and his latest a machine for punching rasps. His death took place at Sheffield on 29th October 1894, at the age of fifty-two. He became a Member of this Institution in 1890.

INDEX.

1894.

Parts 3–4.

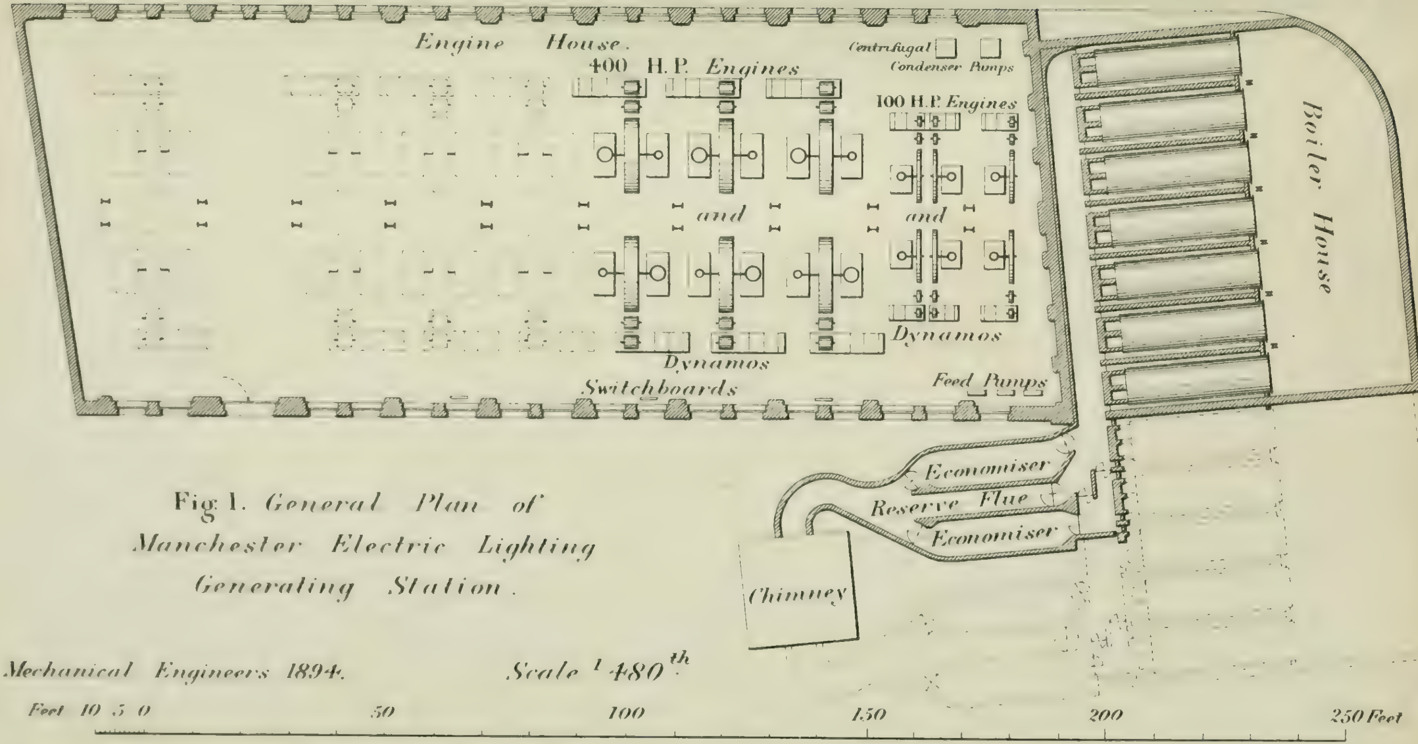


Fig. 1. *General Plan of Manchester Electric Lighting Generating Station.*

Scale 1/480th.

ELECTRIC LIGHTING WORKS.

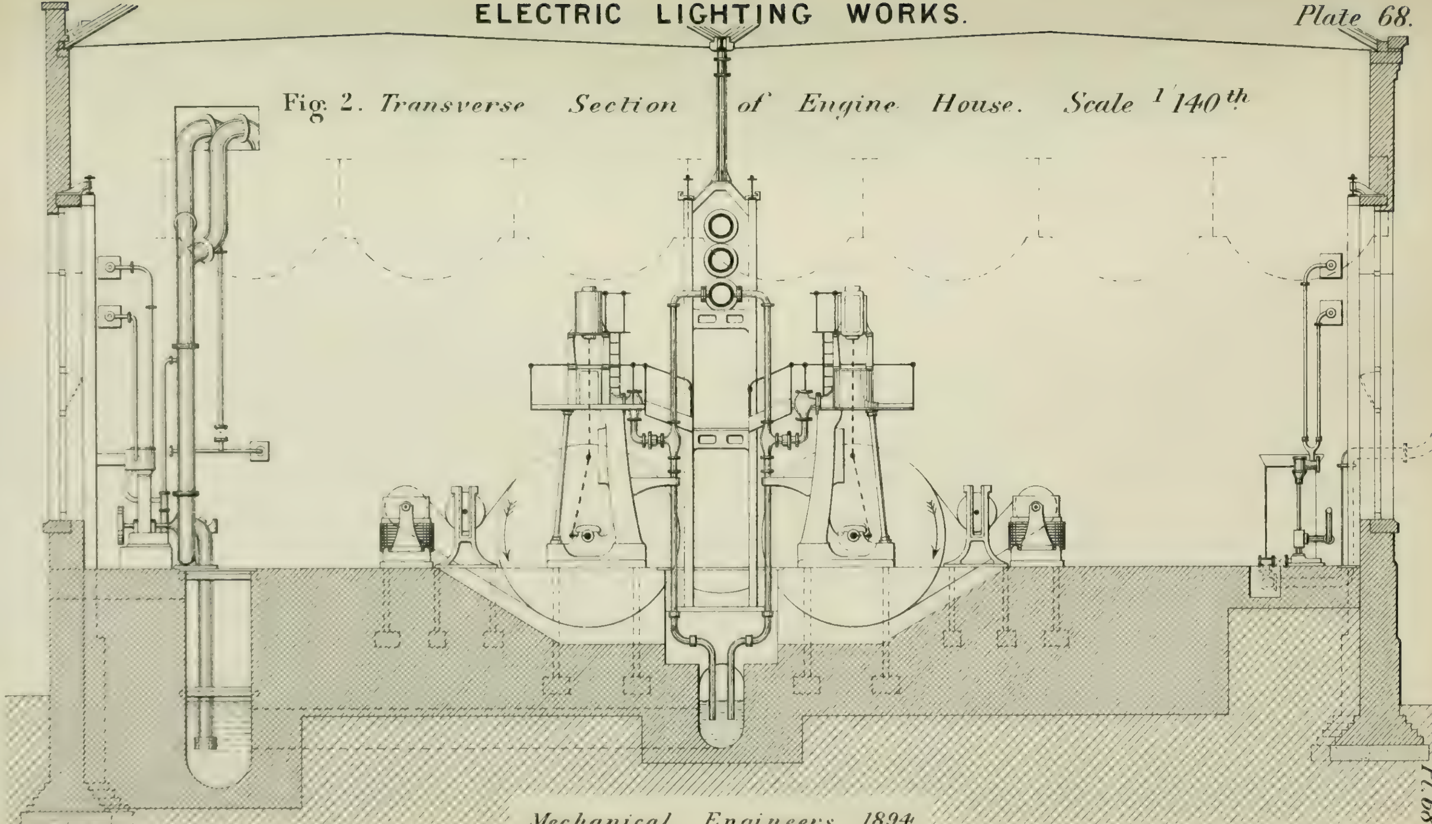
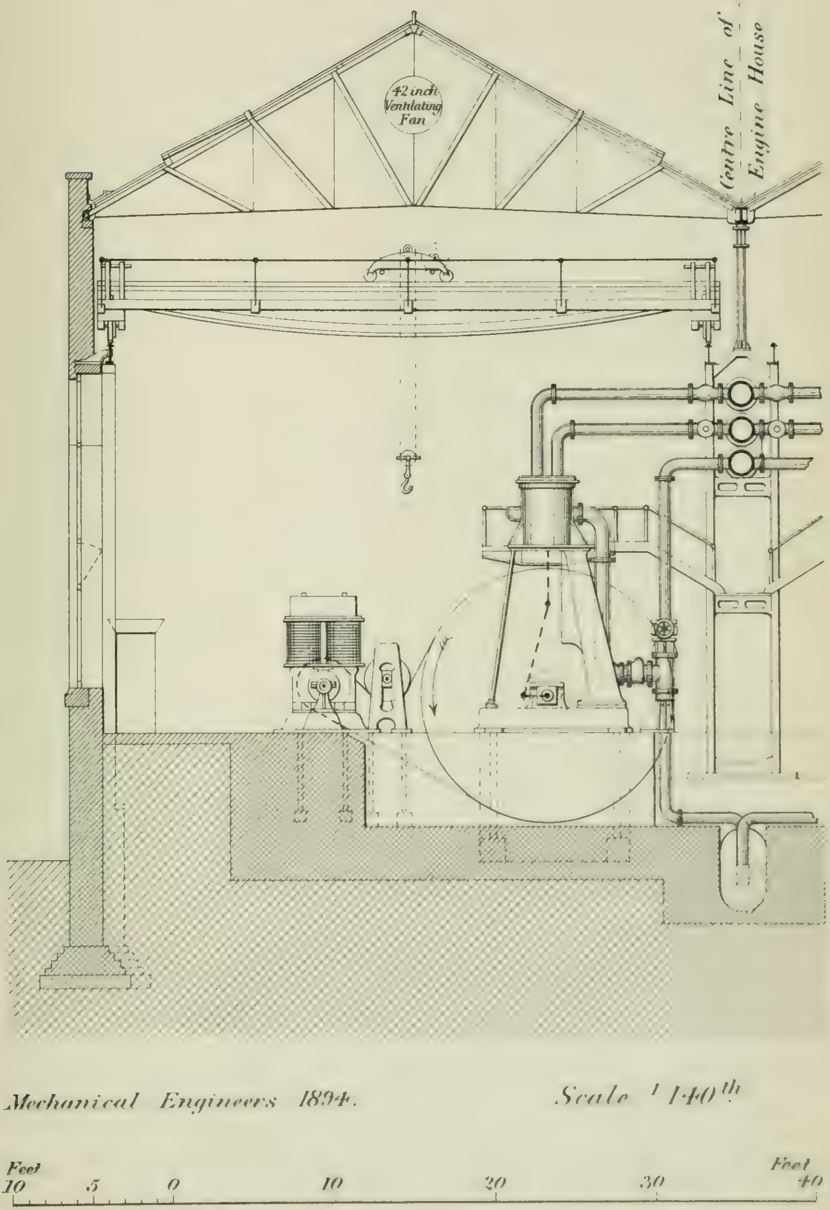


Fig. 2. *Transverse Section of Engine House. Scale 1/140th.*

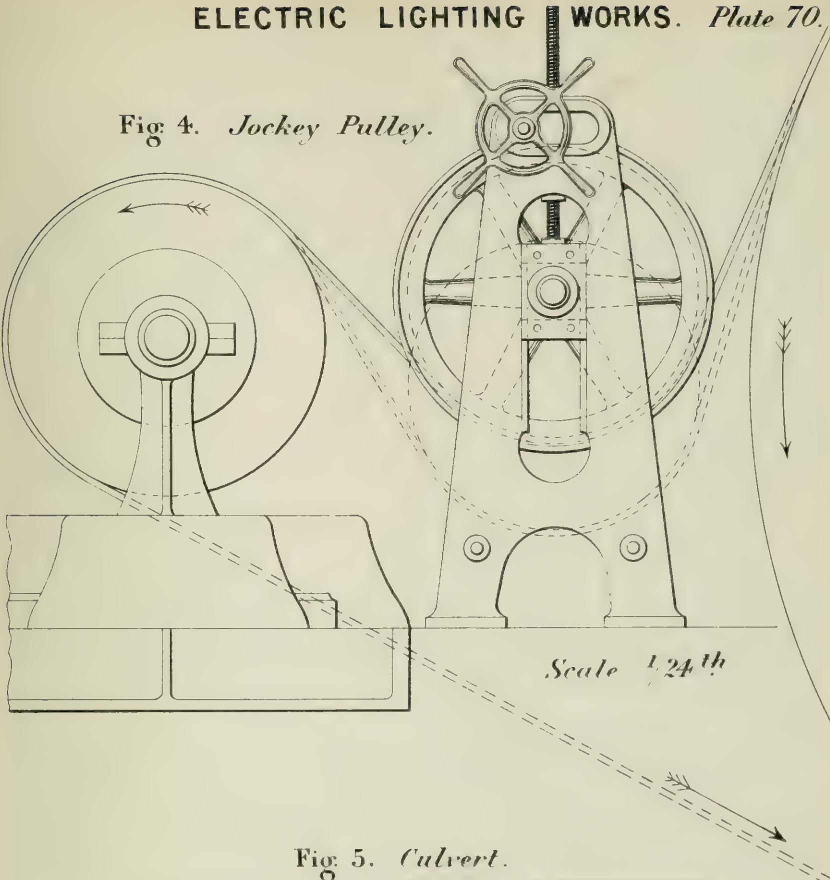
Fig. 3. *Half Transverse Section of Engine House.*



Mechanical Engineers 1894.

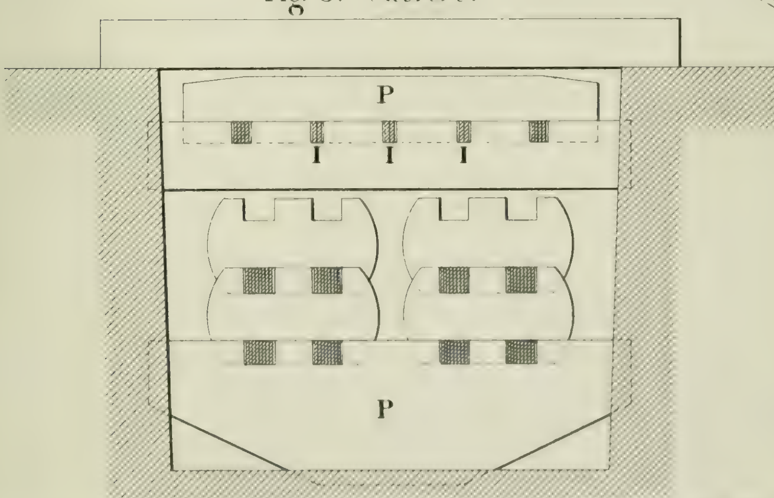
Scale 1/140th

Fig: 4. *Jockey Pulley.*



Scale 1/24th

Fig: 5. *Culvert.*



Scale 1/8th

Fig. 7. *Section of Column supporting Tank.*

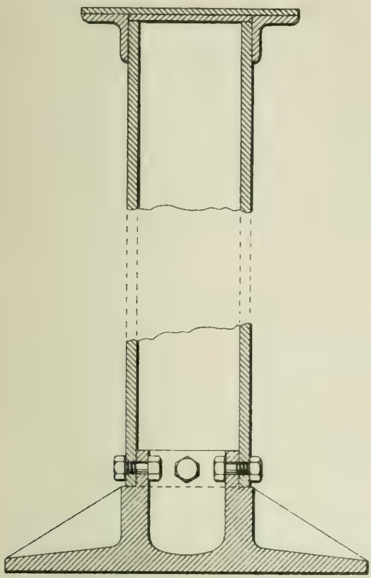


Fig. 6. *Transverse Section of Boiler House. Scale 1/100th.*

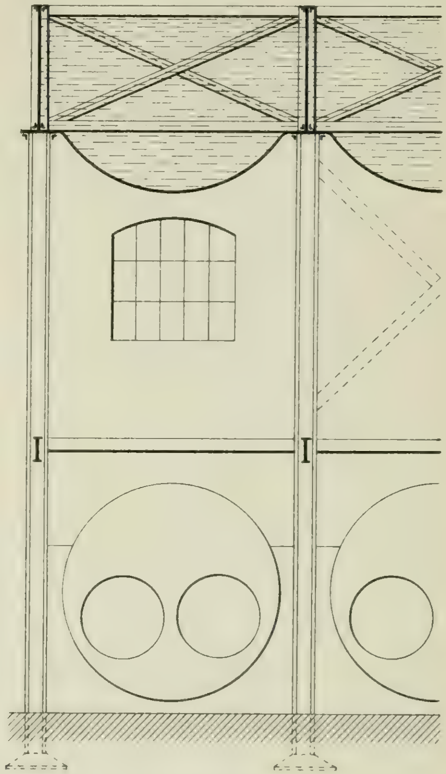


Fig. 8. *Sectional Plan.*

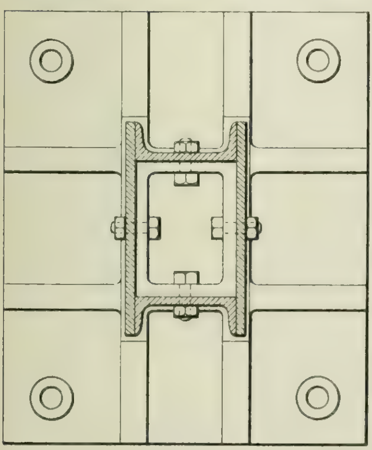
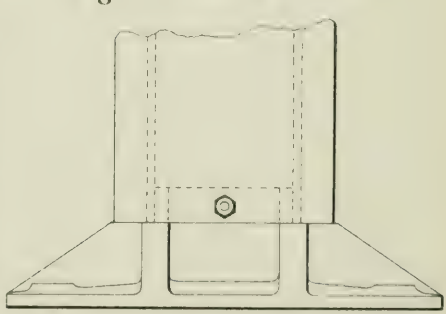


Fig. 9. *Base of Column.*

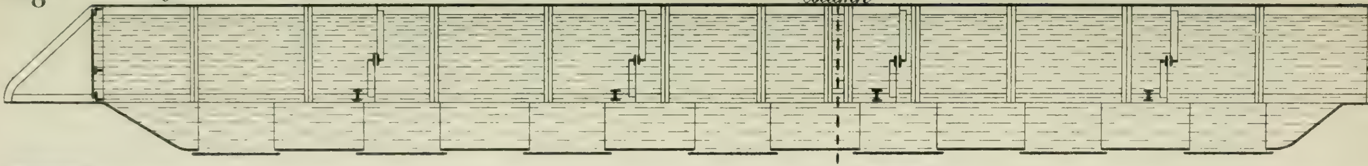


Scale 1/16th.

Inches 12 6 0 1 2 3 Feet

ELECTRIC LIGHTING WORKS.

Fig. 10. *Longitudinal Section of Steel Tank.* *Scale 1/120th.*



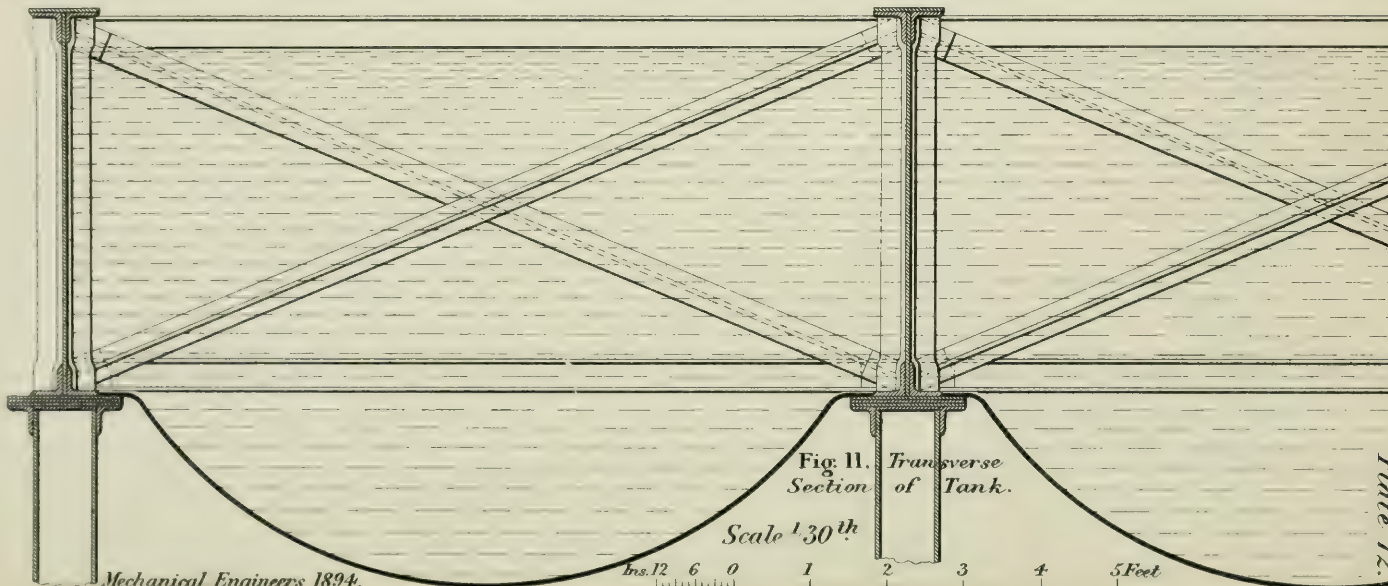
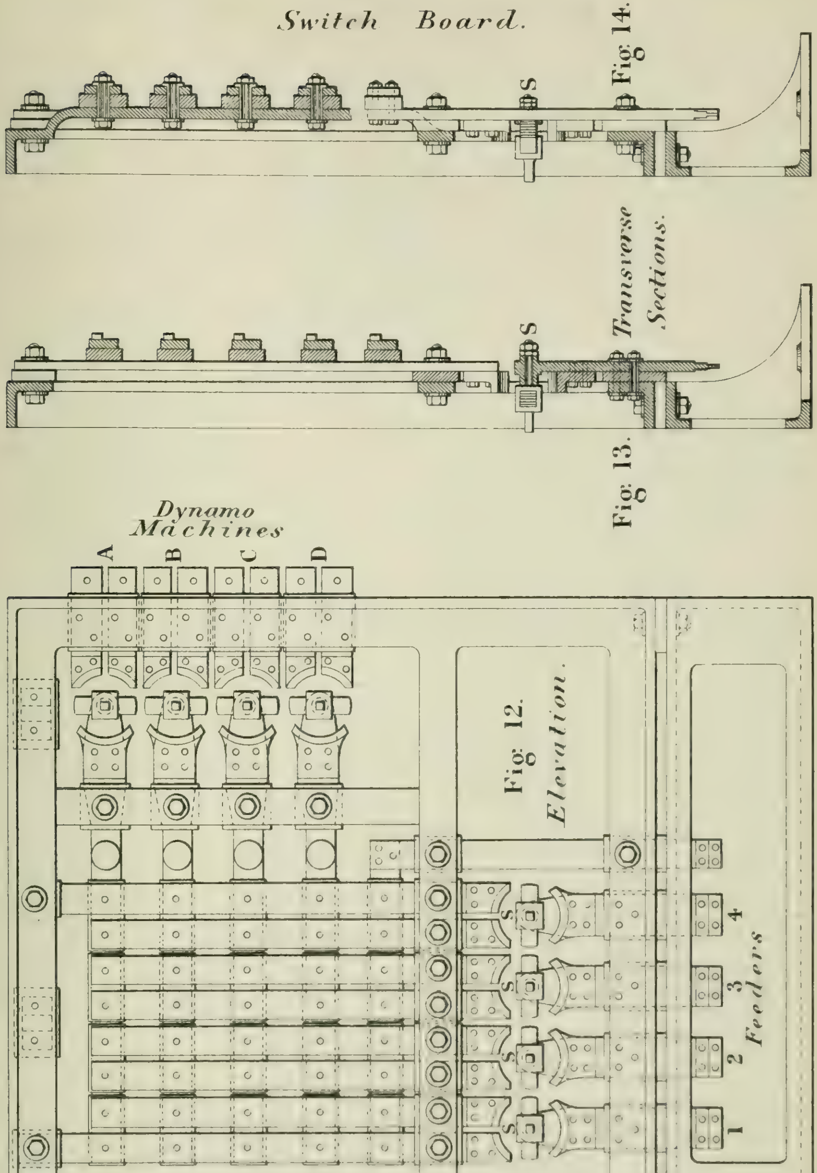


Fig. 11. *Transverse Section of Tank.*

Plate 72.

Switch Board.



Mechanical Engineers 1894.

Scale 1/16th

Ins. 12 6 0 1 2 3 4 Feet

Motor-Generator Machine.

Fig. 15. *Side Elevation.*

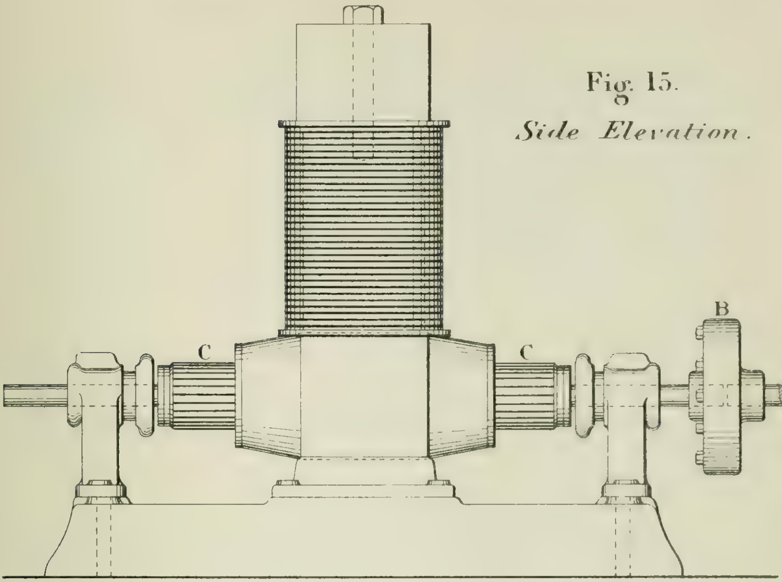
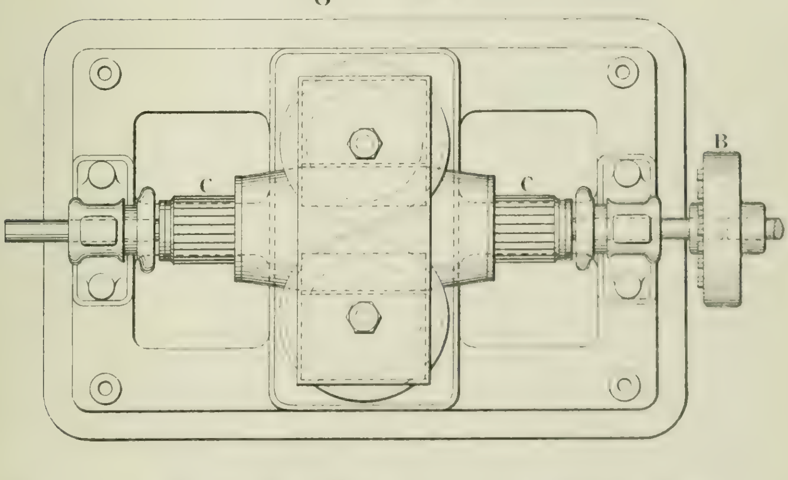


Fig. 16. *Plan.*



Mechanical Engineers 1894. *Scale 1/16th.*

Inches 12 6 0 1 2 3 4 *Feet*

Motor-Generator Machine.

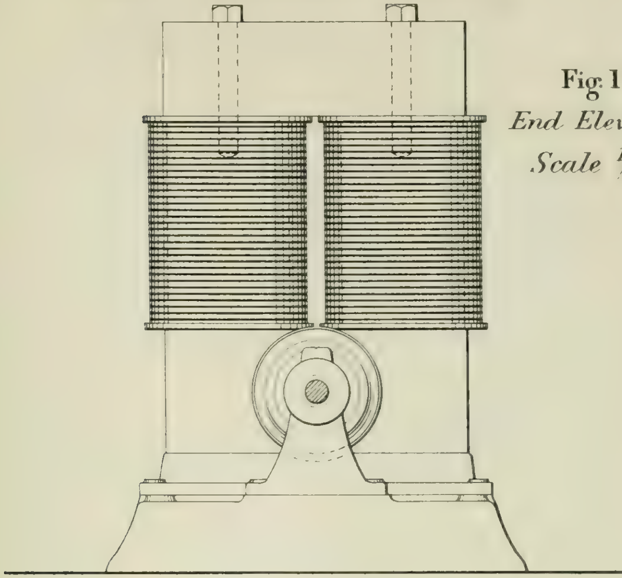


Fig. 17.
End Elevation.
Scale 1/16th

Flexible Coupling.

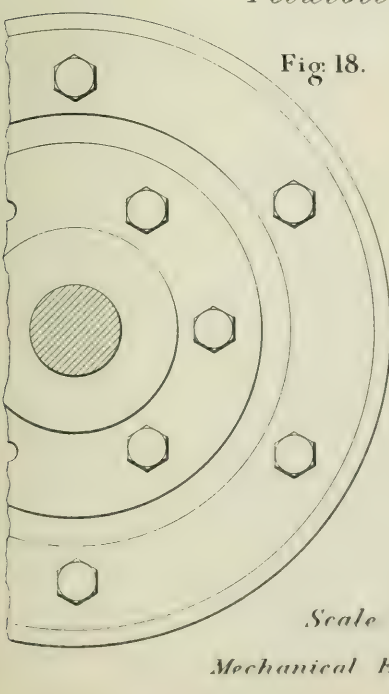


Fig. 18.

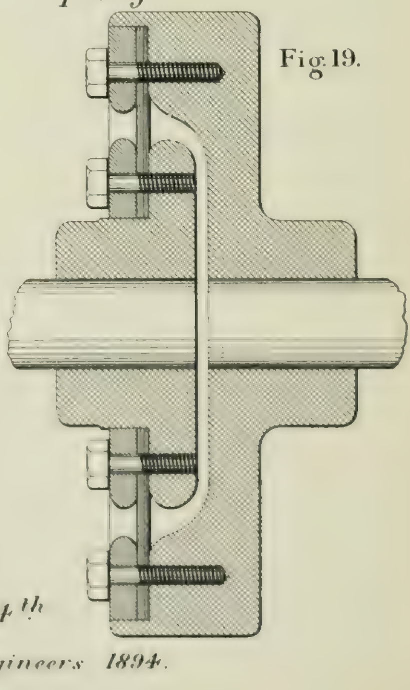


Fig. 19.

Scale 1/4th

ELECTRIC LIGHTING WORKS.

Ball Bearings for Motor-Generator Machine.

Fig. 20. *Longitudinal Section.*

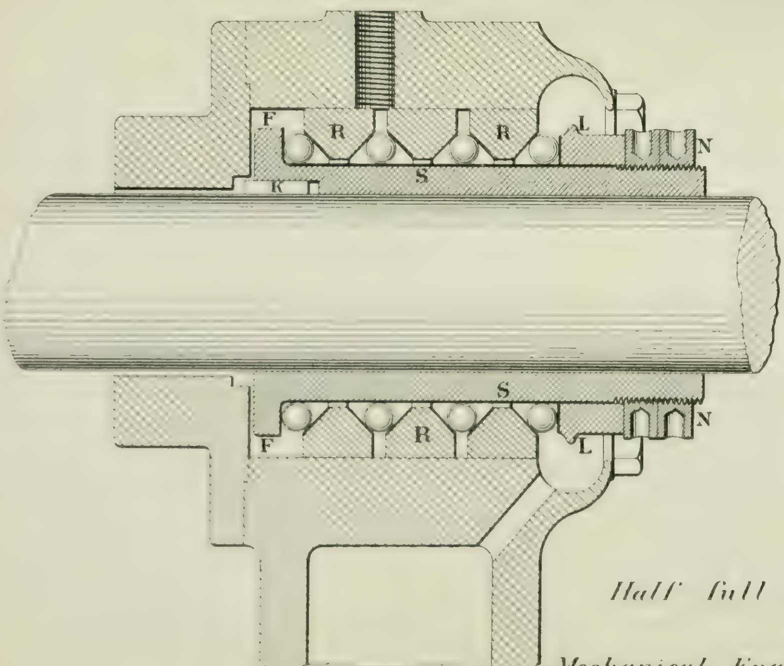
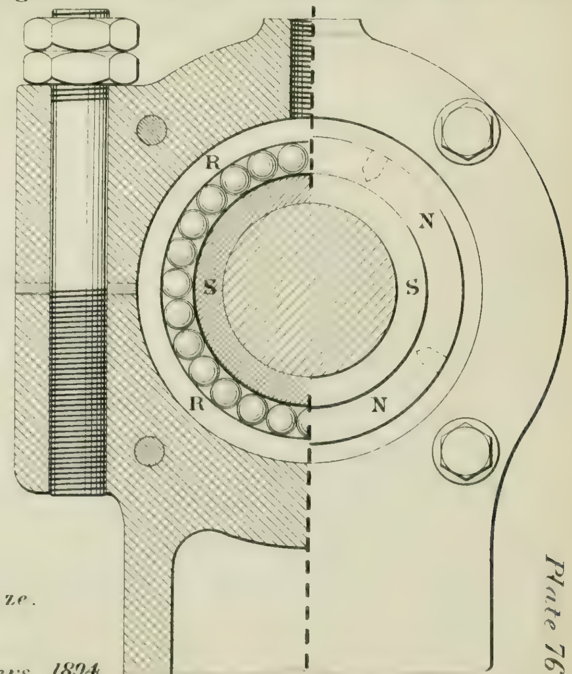


Fig. 21. *Transverse Section and End View.*



Half full size.

Plate 76.

Roller Bearings for Carrying Wheels of Steam Traverser.

Fig: 22.
Plan.

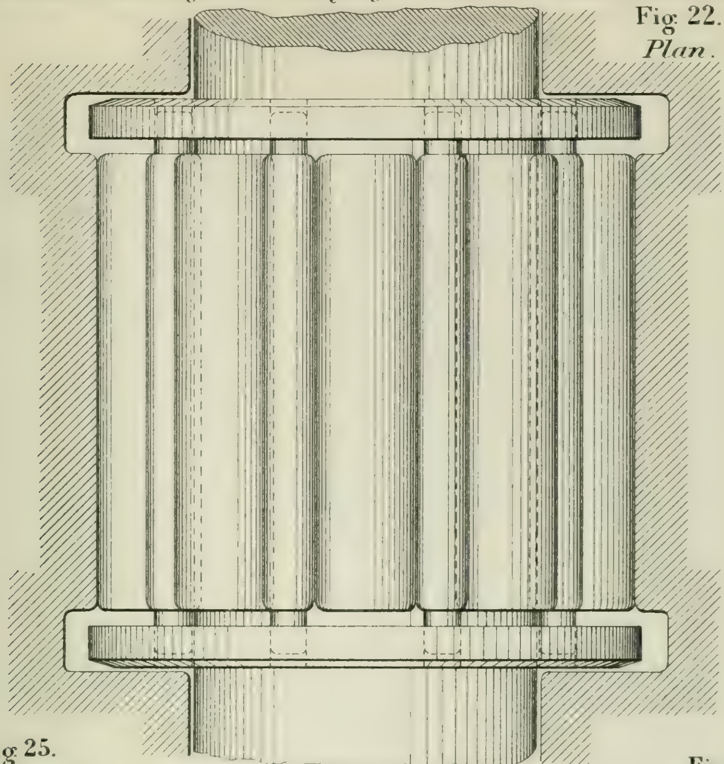


Fig: 25.
Free Roller.

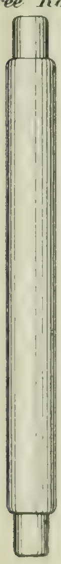


Fig: 23. *Transverse Section.*

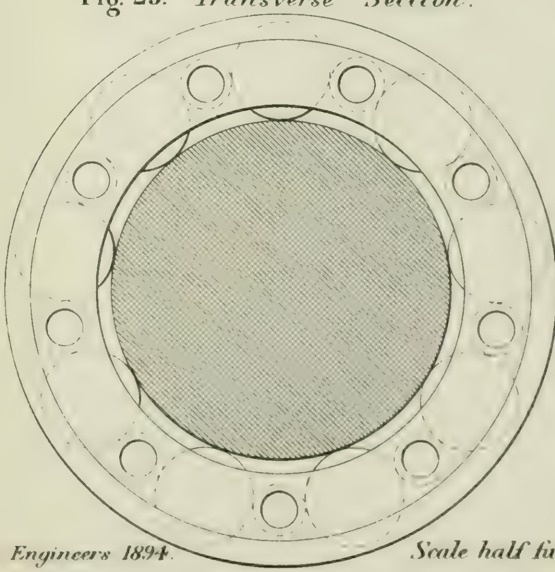


Fig: 24.
Carrying Roller.

 Scale half full size.

Fig. 1. *Dynamo, Exciter, and Switchboard.*

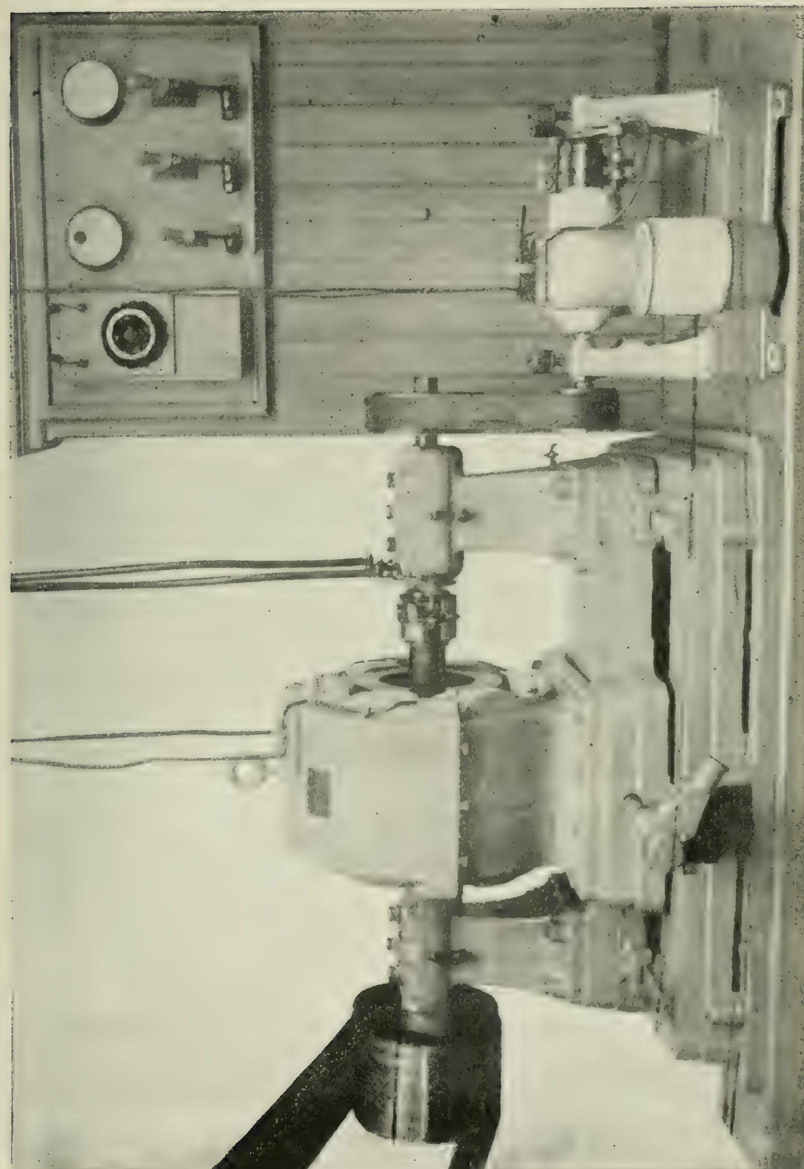


Fig. 2. *Reactive Coil, Switchboard, and Welder, with Bars ready to weld.*

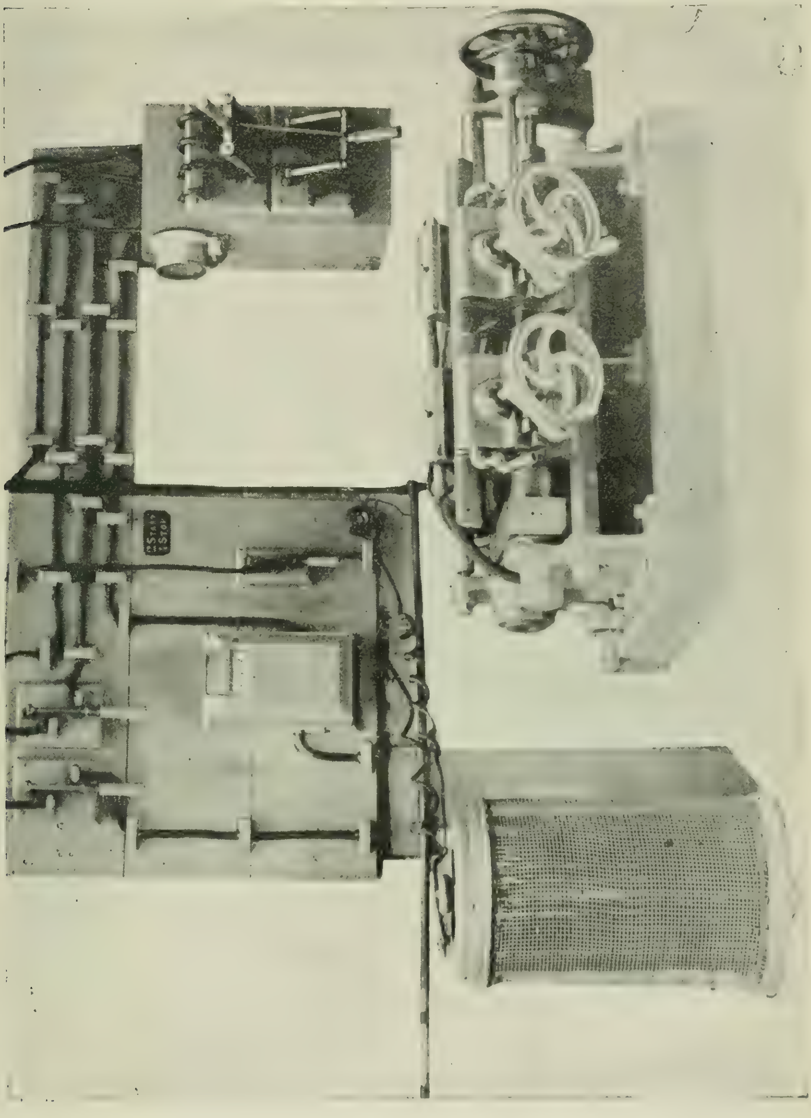
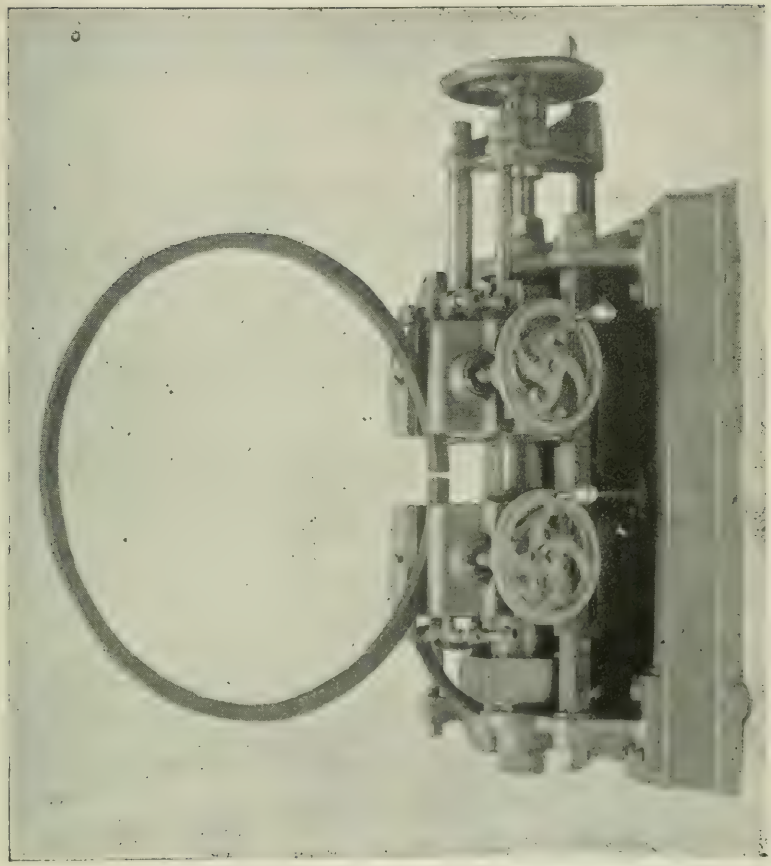


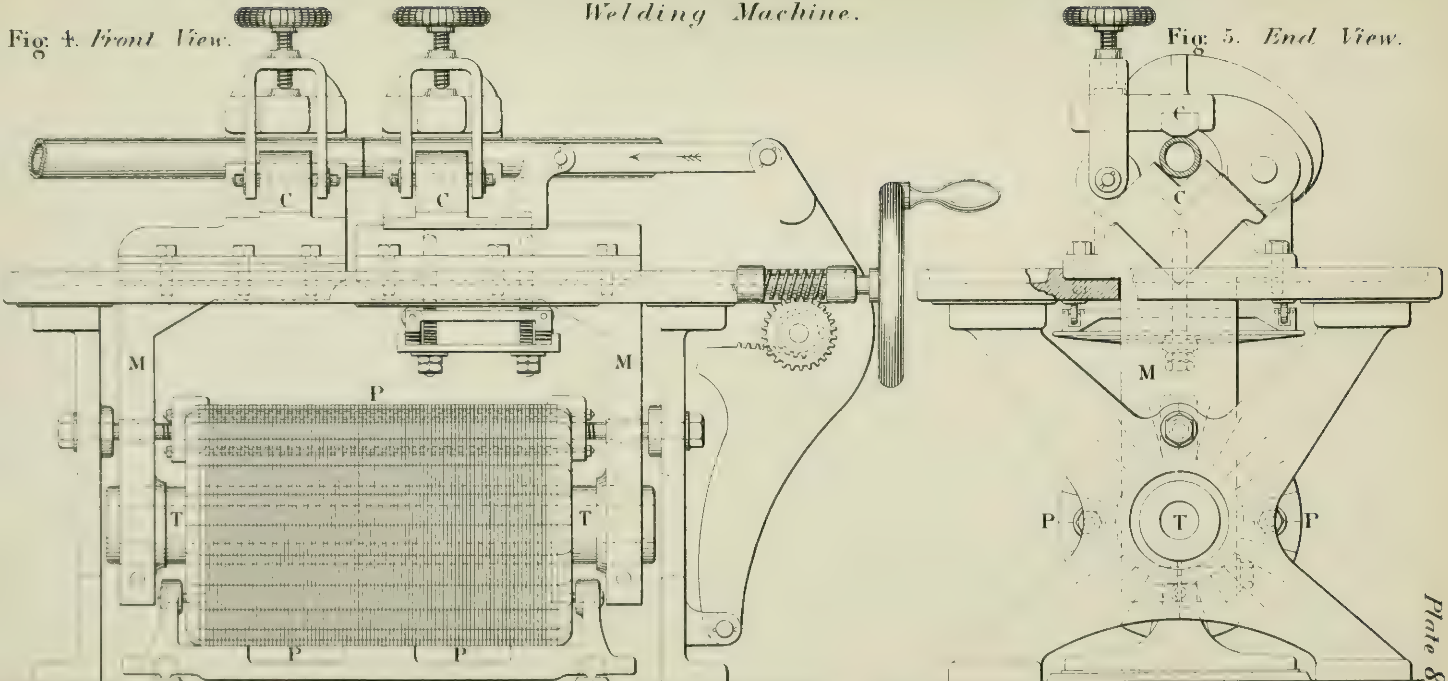
Fig. 3. *Welder with Hoop ready to weld.*



ELECTRIC WELDING.

Welding Machine.

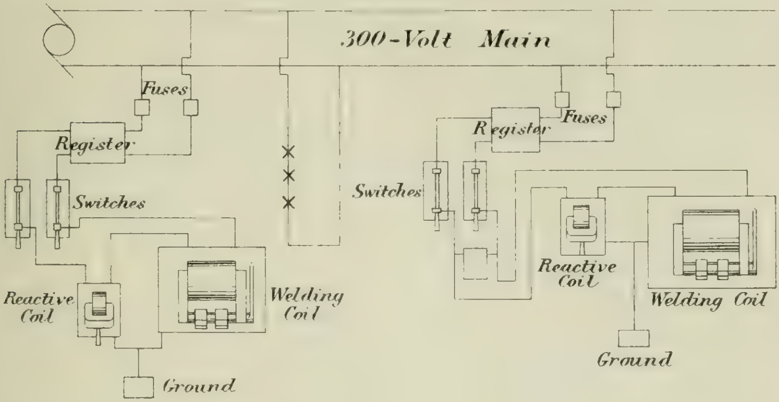
Fig. 4. *Front View.* Fig. 5. *End View.*



Scale $^1/_{8}$th

Plate 81.

Fig. 6. *General Plan of Two Welders arranged in parallel, on constant potential circuit.*



Simple Transformer.

Fig. 7. *Plan.*

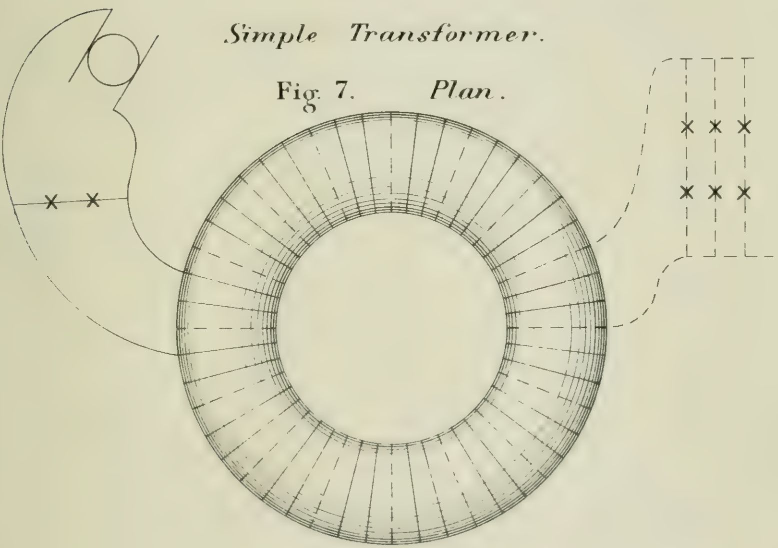


Fig. 8. *Transverse Section.*

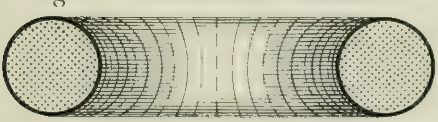


Fig: 9. *Welding Transformer.*

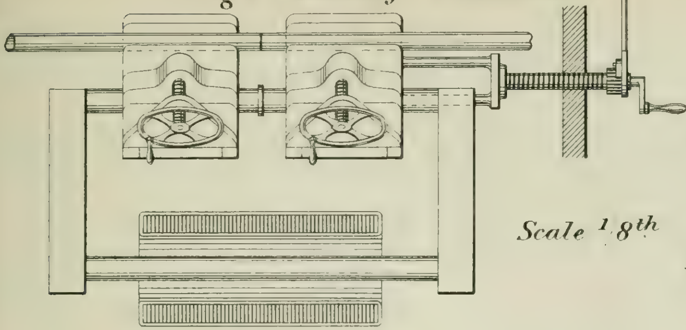
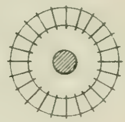


Fig: 10. *Transverse Section of Core.*



Scale 1/8th

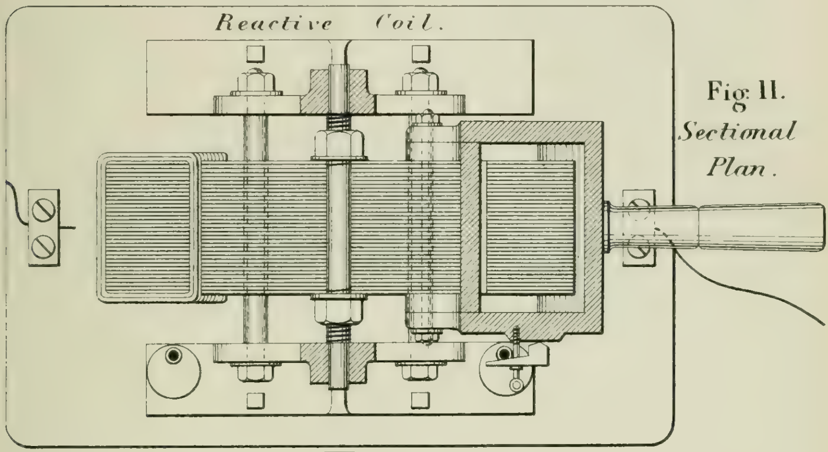
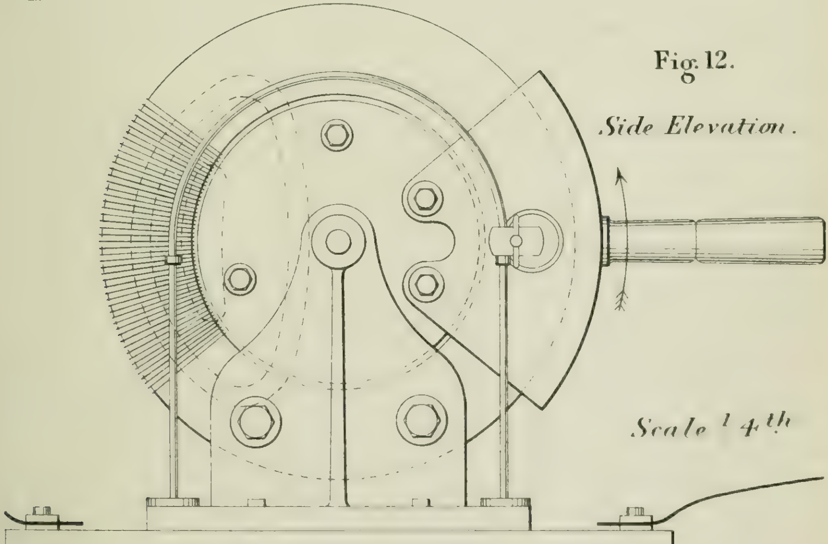


Fig: 11. *Sectional Plan.*

Fig: 12. *Side Elevation.*



Scale 1/4th

Tube Welding.

Fig: 13. *Butt Joint.*

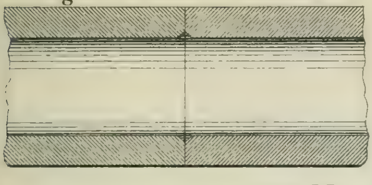


Fig: 14. *Lap Joint.*

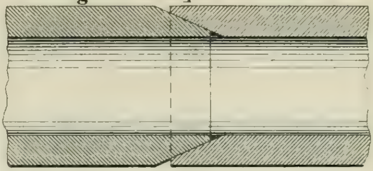


Fig: 15. *Upsetting.*

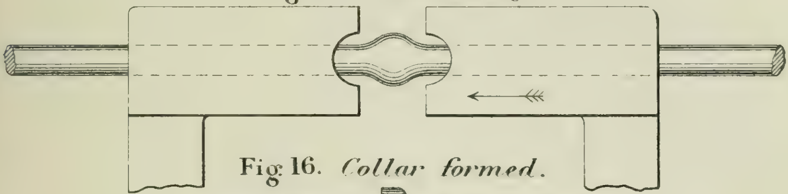
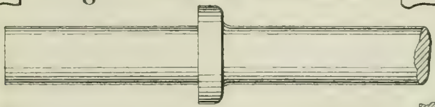


Fig: 16. *Collar formed.*



Riveting.

Fig: 17.

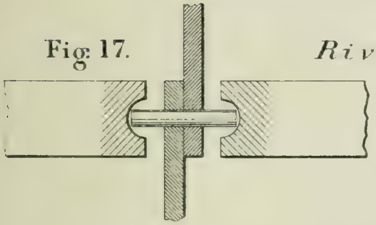


Fig: 18.

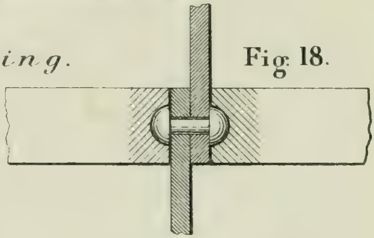
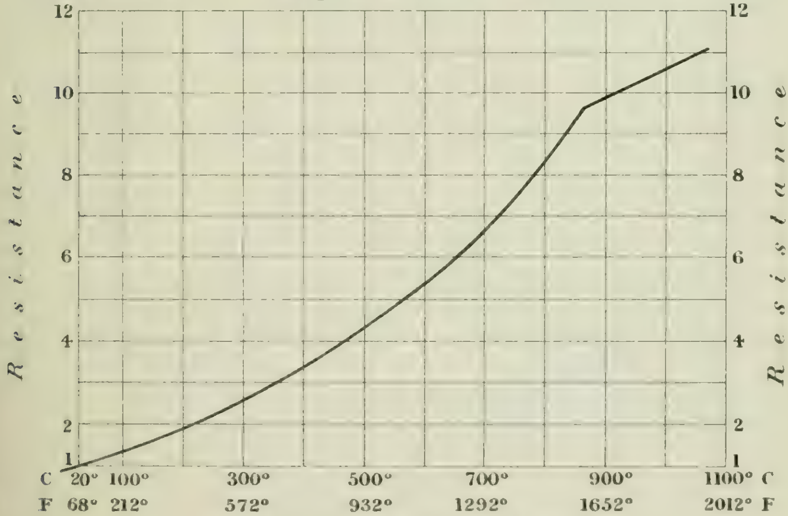


Fig: 19. *Increase of Resistance due to Increase of Temperature in Soft Iron Wire.*



Mechanical Engineers 1894.

Fig. 1. "*Newry.*"

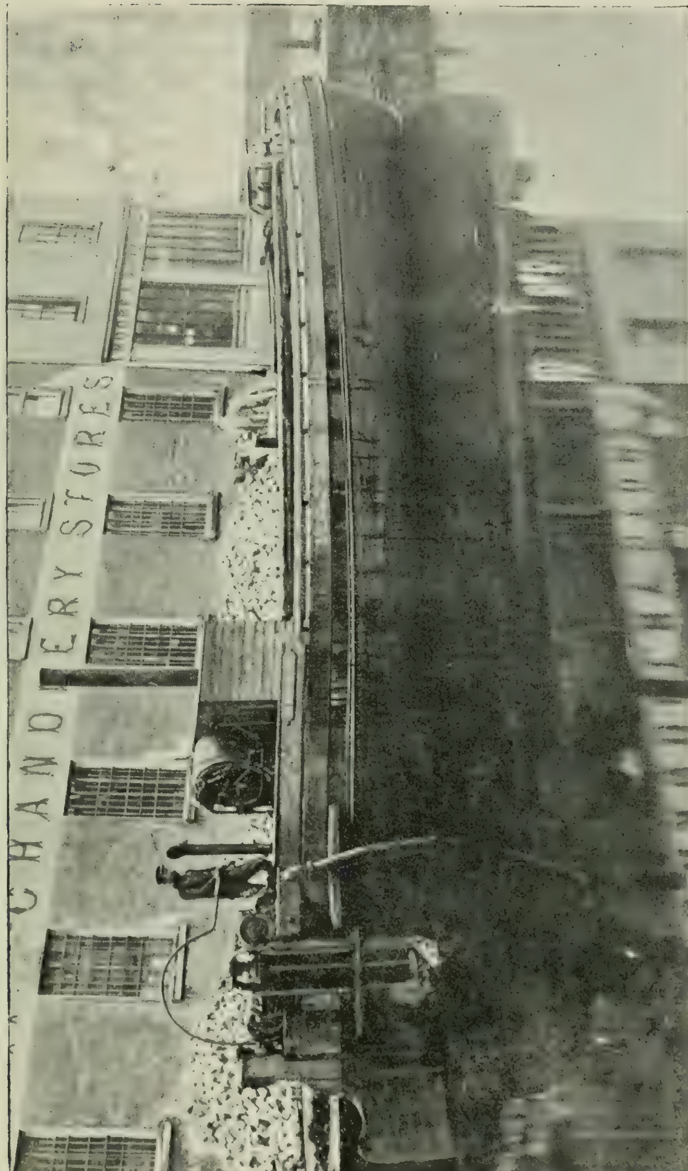
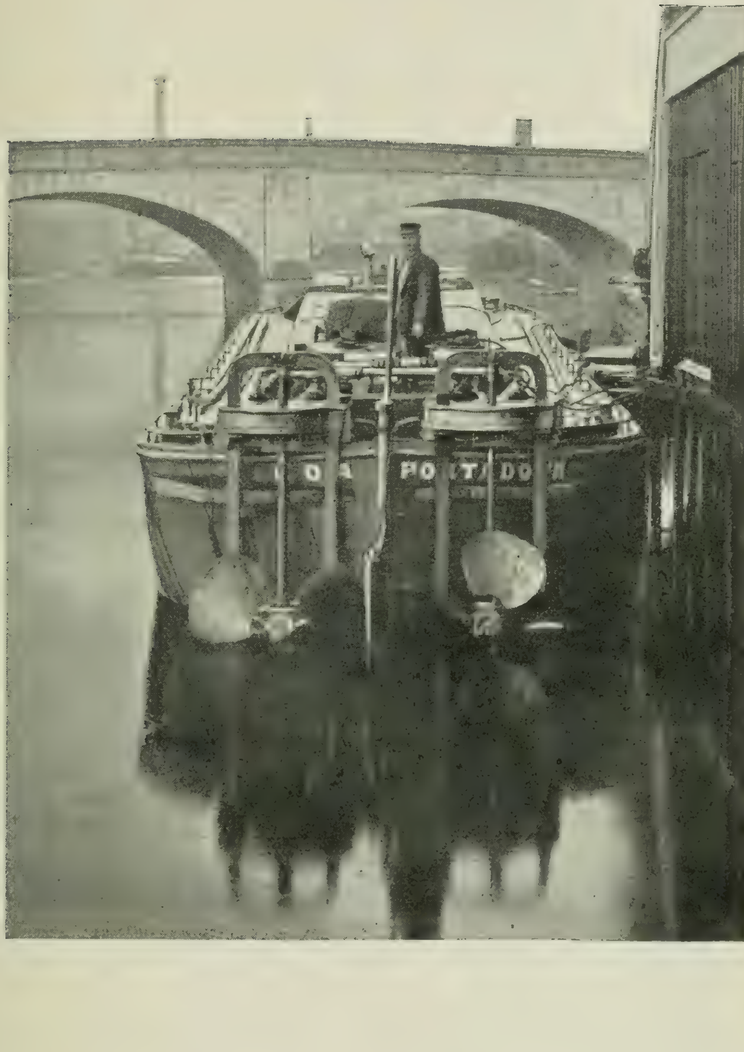
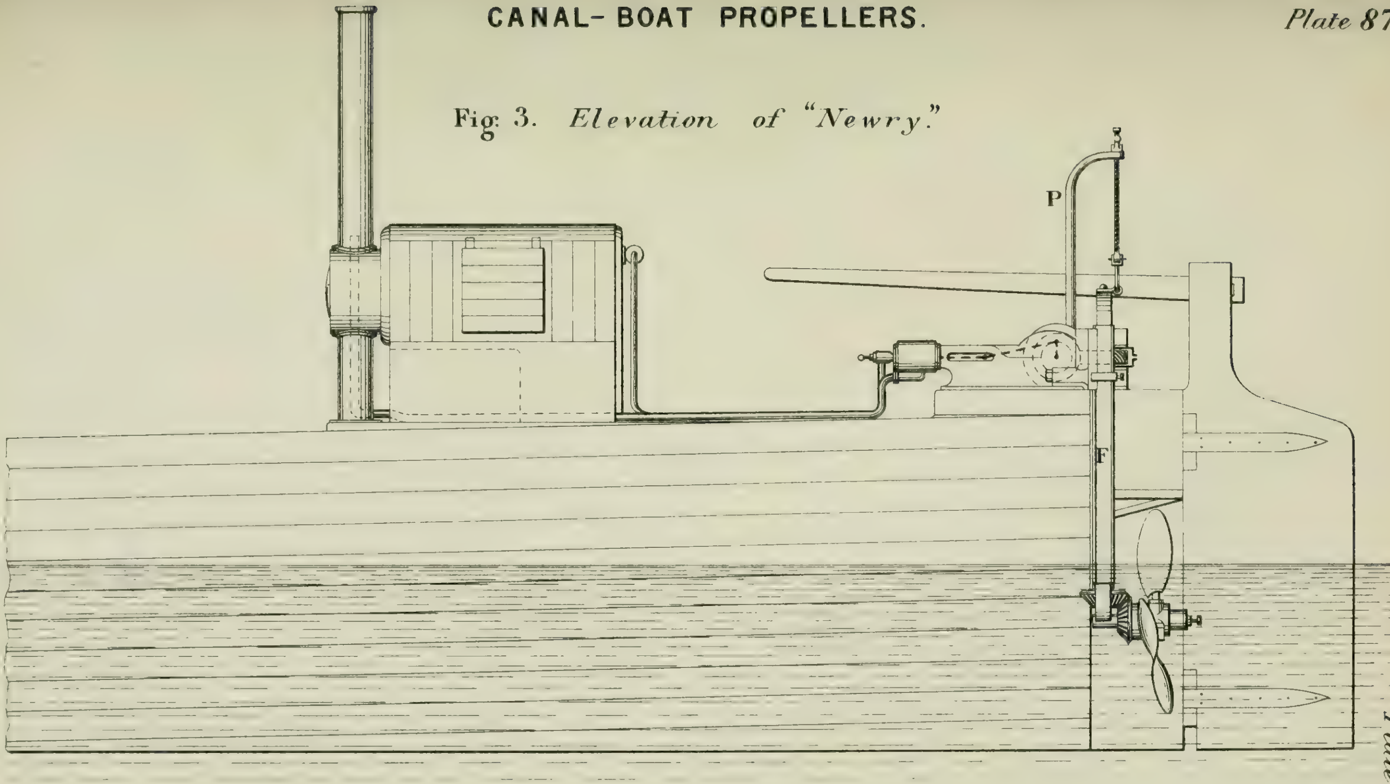


Fig. 2. *Stern view of "Hilda."*



CANAL-BOAT PROPELLERS.

Fig. 3. *Elevation of "Newry."*



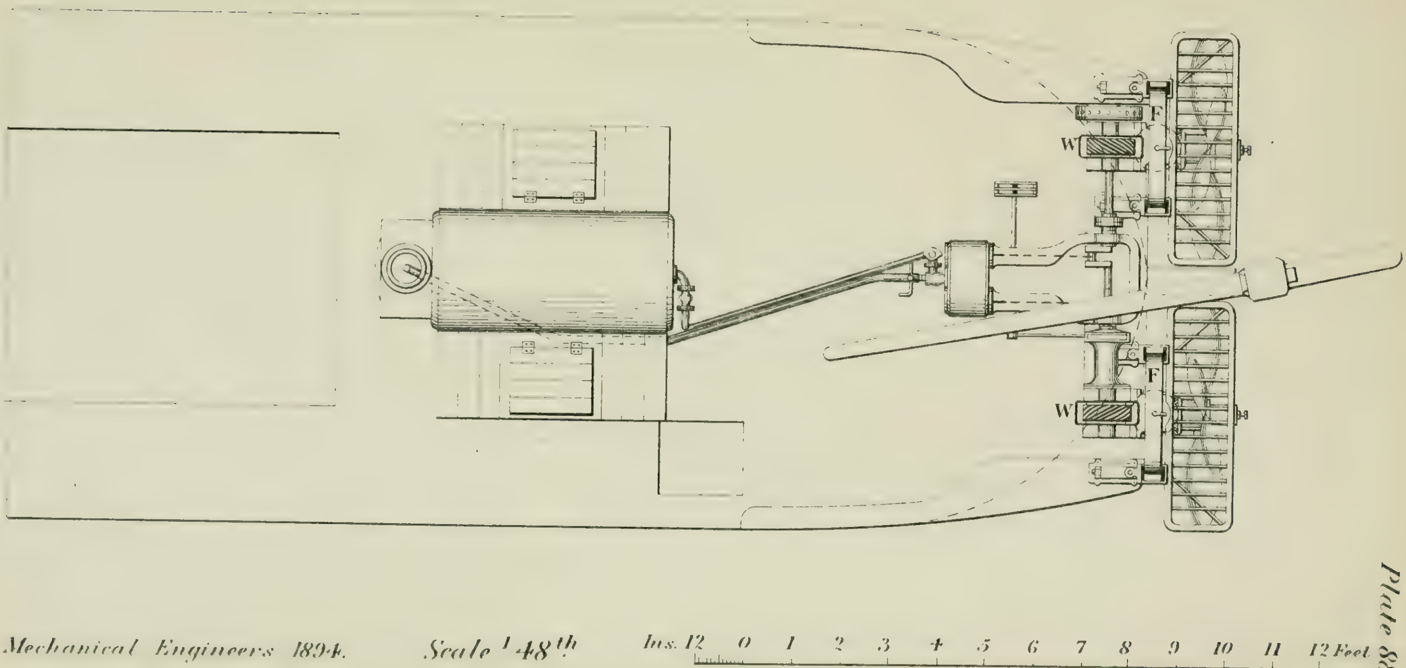
Scale 1/48th.

Ins. 12 0 1 2 3 4 5 6 7 8 9 10 11 12 Feet

Plate 87.

CANAL-BOAT PROPELLERS.

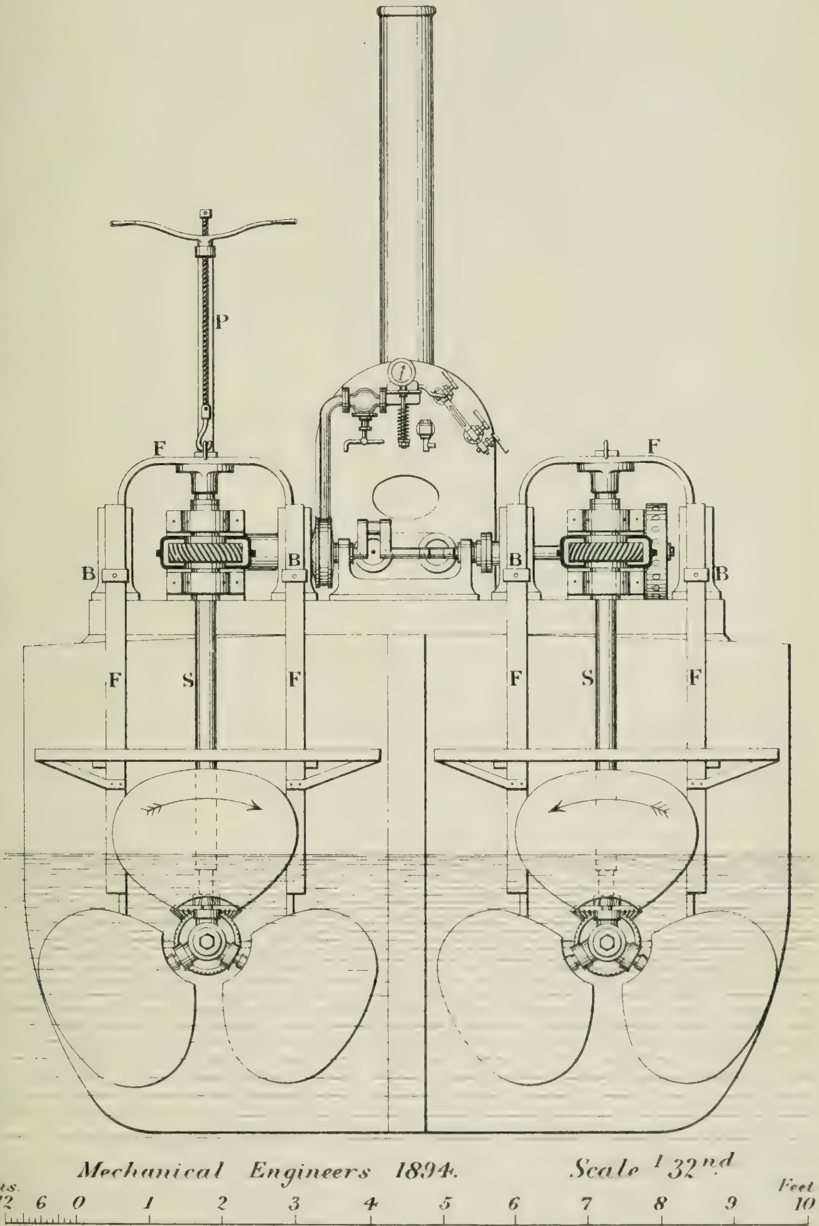
Fig. 4. *Plan of "Newry."*



Mechanical Engineers 1894. *Scale 1/48th*

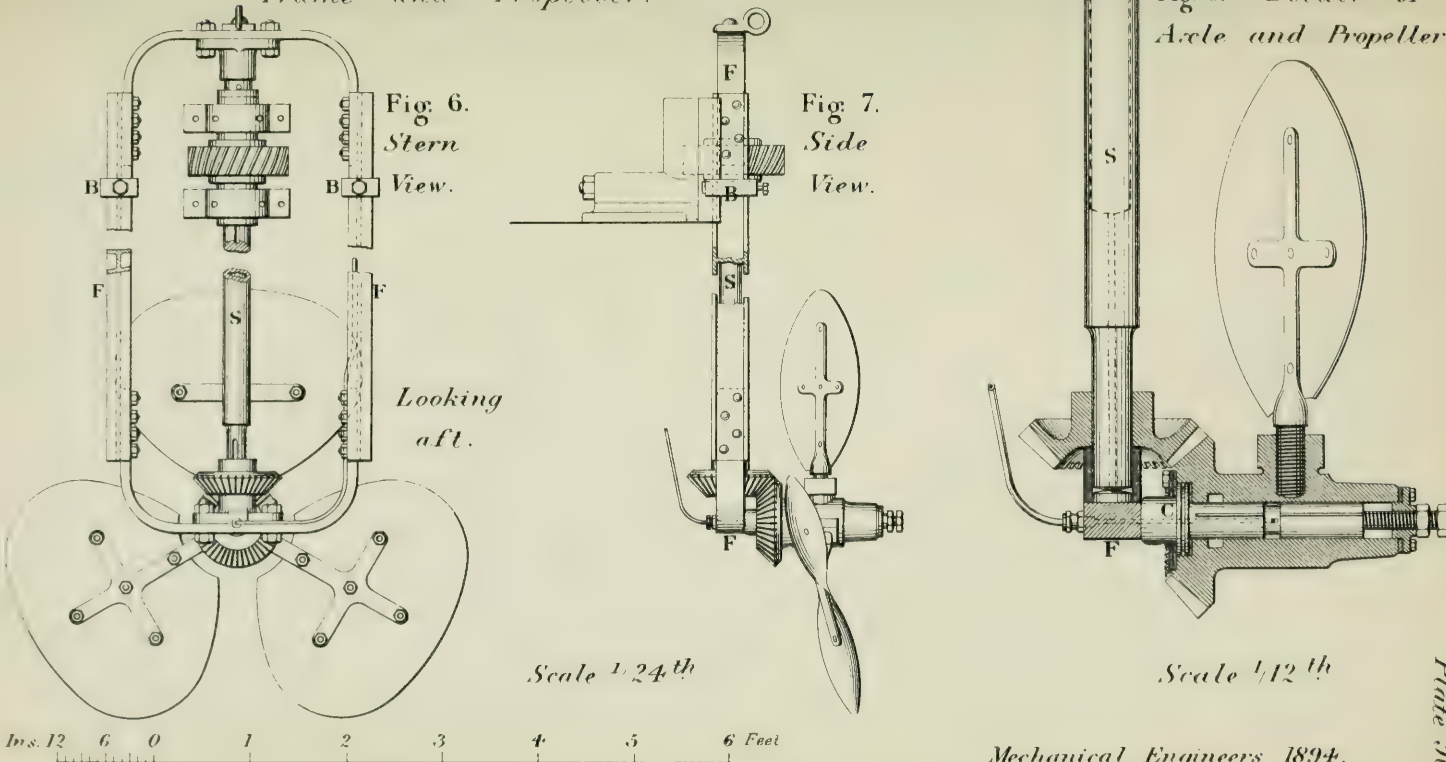
Plate 88.

Fig. 5. *Stern View of "Newry."*



Mechanical Engineers 1894. *Scale 1/32nd.*

CANAL-BOAT PROPELLERS.



Frame and Propeller.

Fig. 6. Stern View. Looking aft.

Fig. 7. Side View.

Scale 1/24th

Fig. 8. Detail of Axle and Propeller.

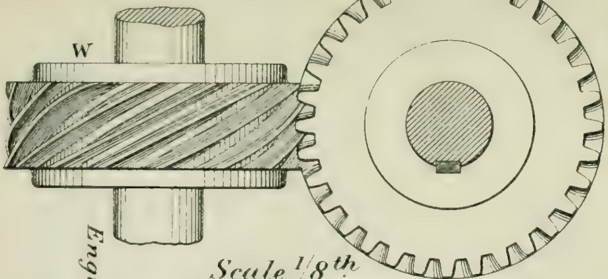
Scale 1/12th

Plate 90.

CANAL-BOAT PROPELLERS.

Skew Wheels.

Fig. 9. *Plan.*



Scale 1/8th.

Fig. 10. *Elevation.*

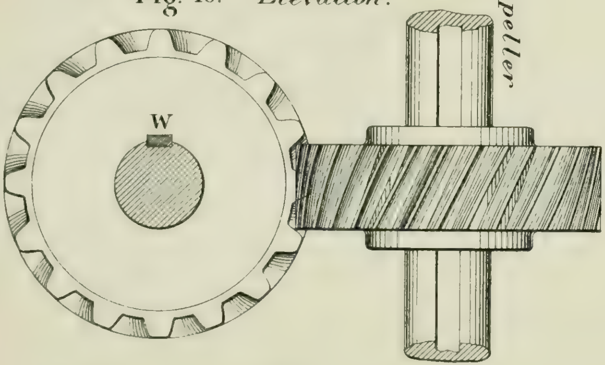


Fig. 11. *Driving by Petroleum Engine.*

Scale 1/48th.

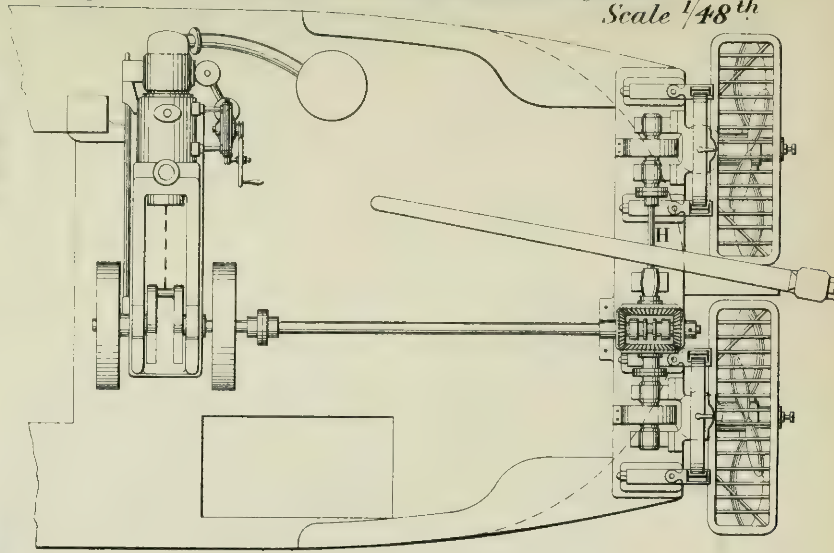


Fig. 12.

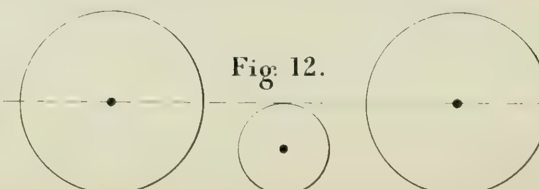


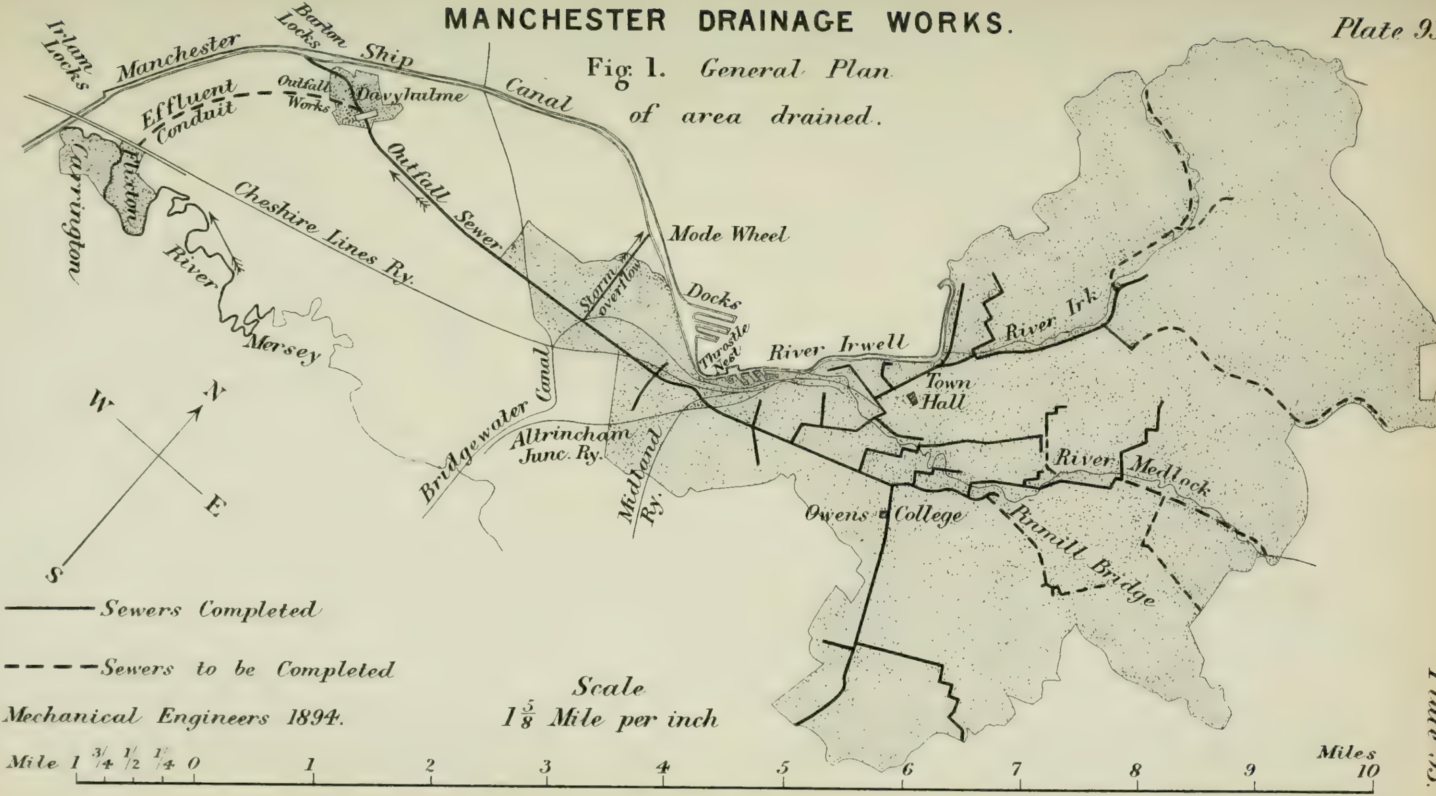
Plate 91.

Fig. 13. *Canal Map. North-East of Ireland.*

Mechanical Engineers 1894. *Scale 30 miles per inch.*

MANCHESTER DRAINAGE WORKS.

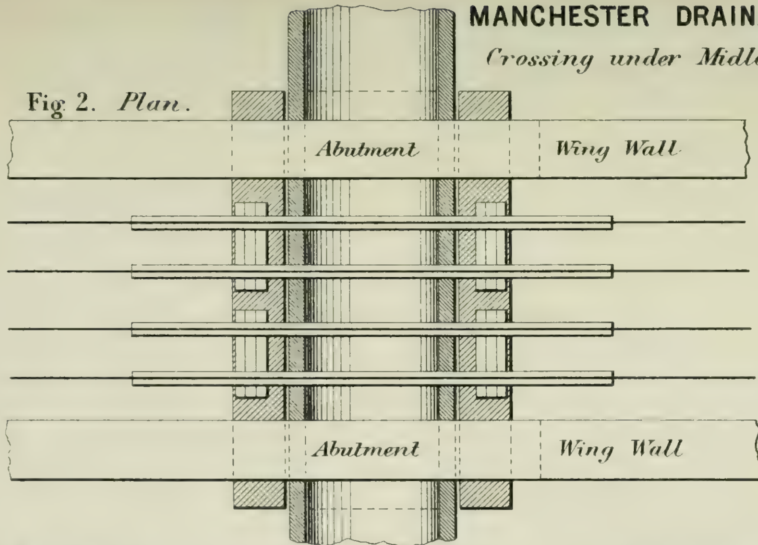
Fig. 1. General Plan of area drained.



MANCHESTER DRAINAGE WORKS.

Crossing under Midland Railway.

Fig. 2. *Plan.*



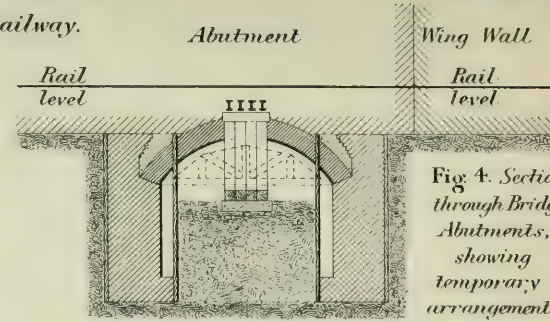


Fig. 4. *Section through Bridge Abutments, showing temporary arrangements.*

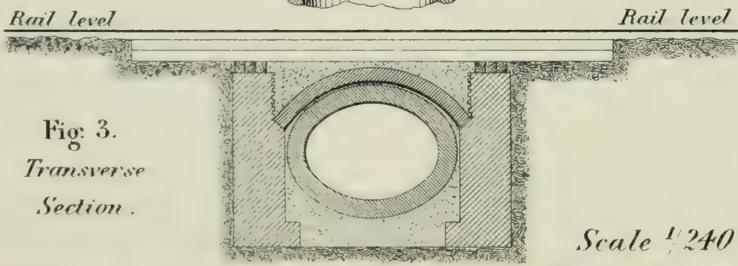


Fig. 3. *Transverse Section.*

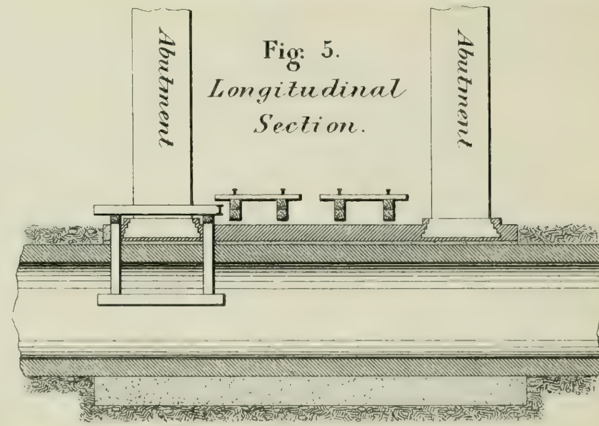
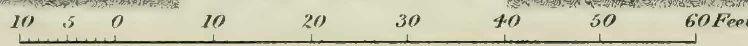


Fig. 5. *Longitudinal Section.*

Scale 1/240th.



MANCHESTER DRAINAGE WORKS.

Storm Overflow Chamber.

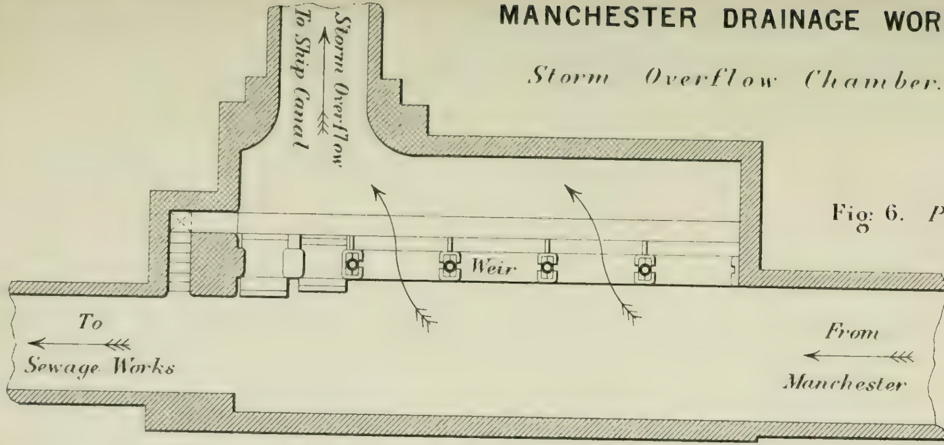


Fig: 6. Plan.

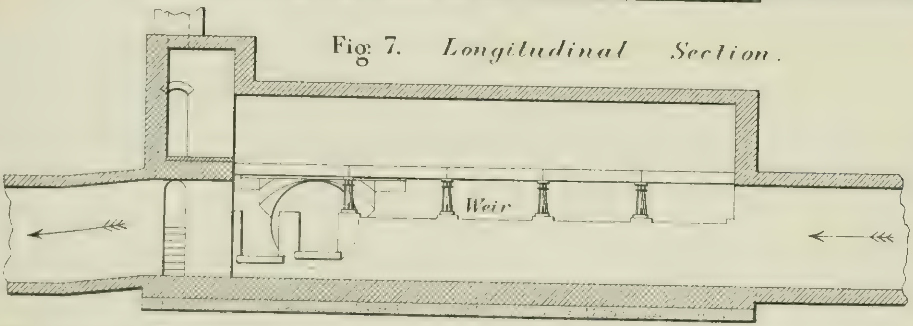


Fig: 7. Longitudinal Section.

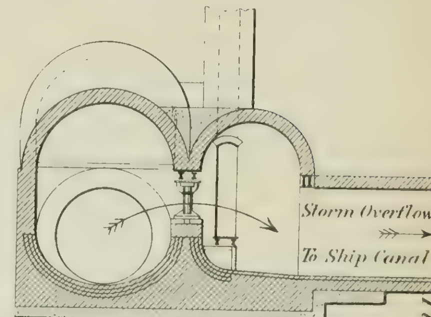


Fig: 8. Transverse Section.

Scale 1/240th

10 5 0 10 20 30 40 50 60 70 80 90 Feet

Plate 95.

MANCHESTER DRAINAGE WORKS.

Bridgewater Canal Crossing.

Fig. 9. Plan.

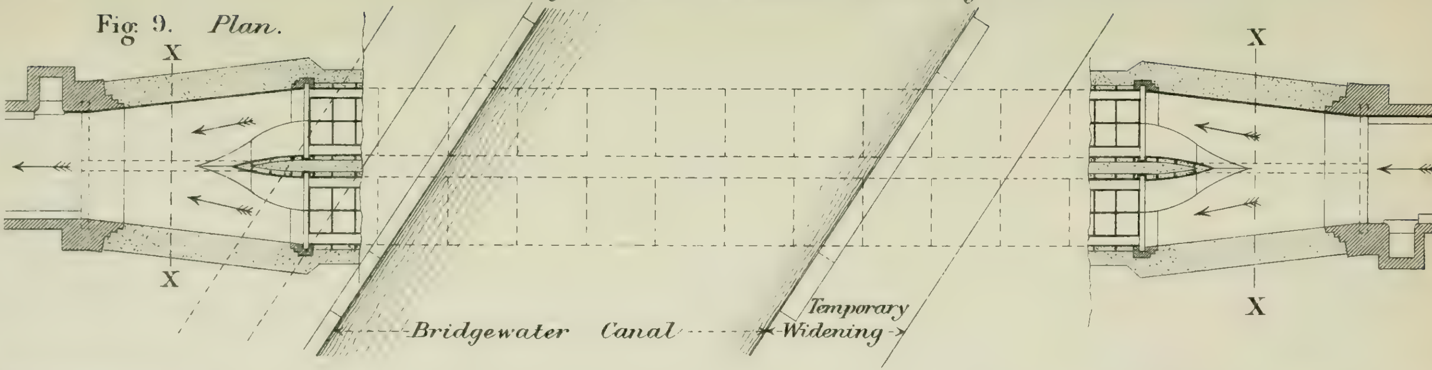
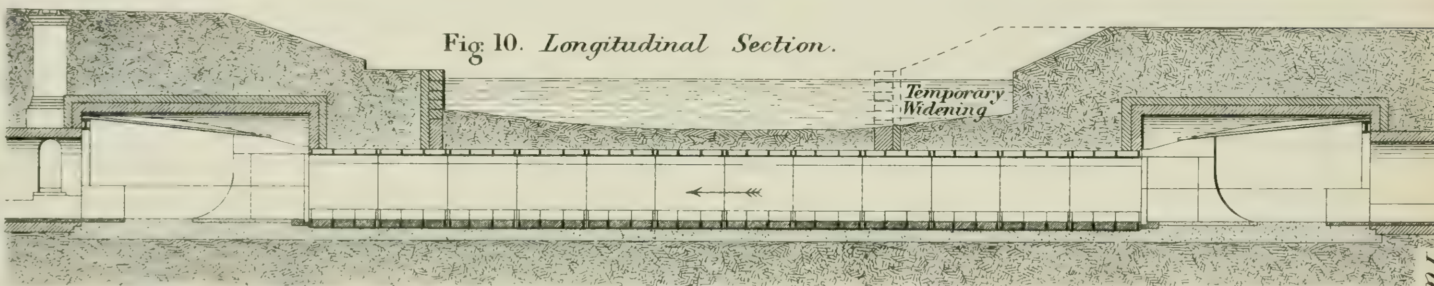


Fig. 10. Longitudinal Section.



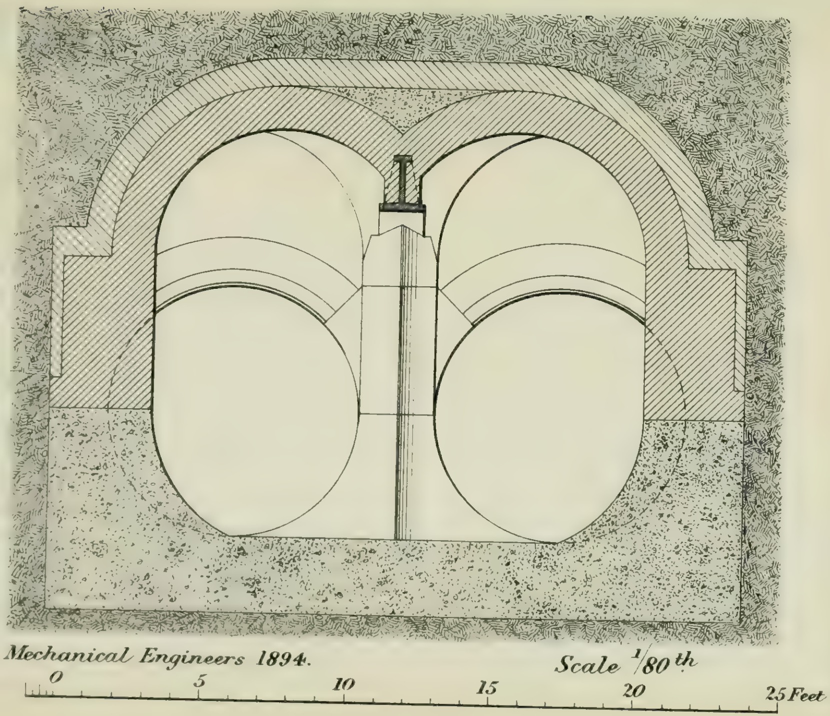
Scale 1/300th

Feet 10 5 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 Feet

Plate 96.

MANCHESTER DRAINAGE WORKS.

Fig. 11. *Section at XX, Fig. 9.*



Scale 1/80th

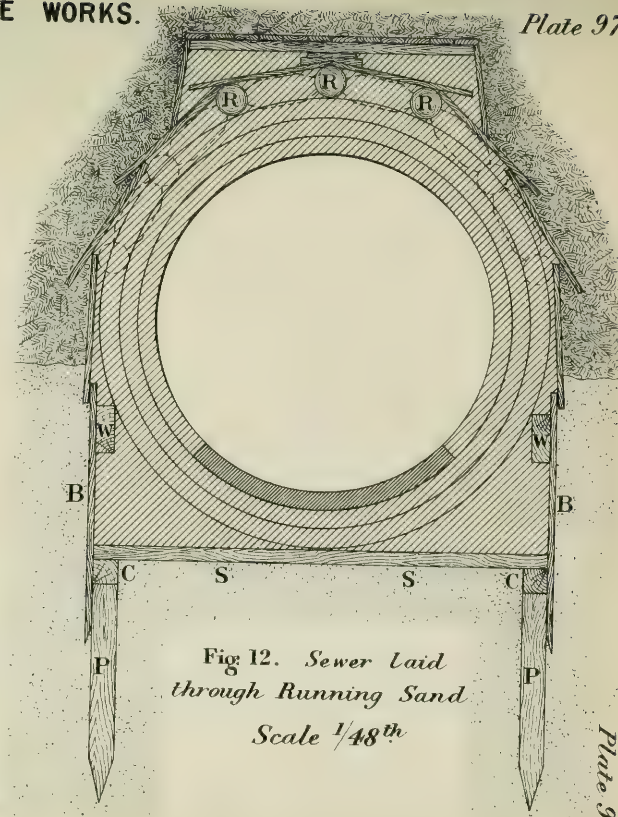


Fig. 12. *Sewer Laid through Running Sand*

Scale 1/48th

Plate 97.

MANCHESTER DRAINAGE WORKS.

Bridgewater Canal Crossing.

Cast - Iron Cylinders.

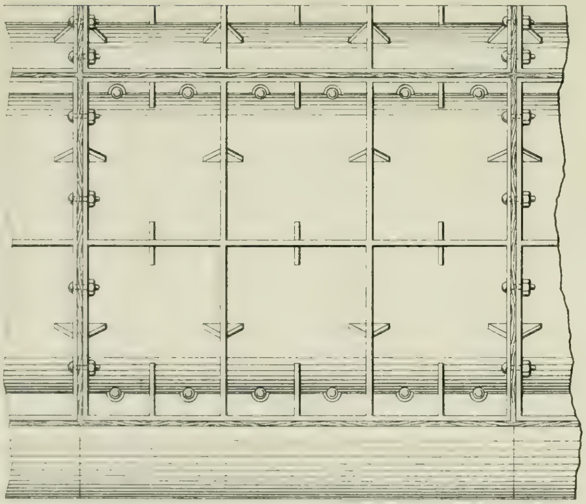


Fig. 13. *Elevation.*

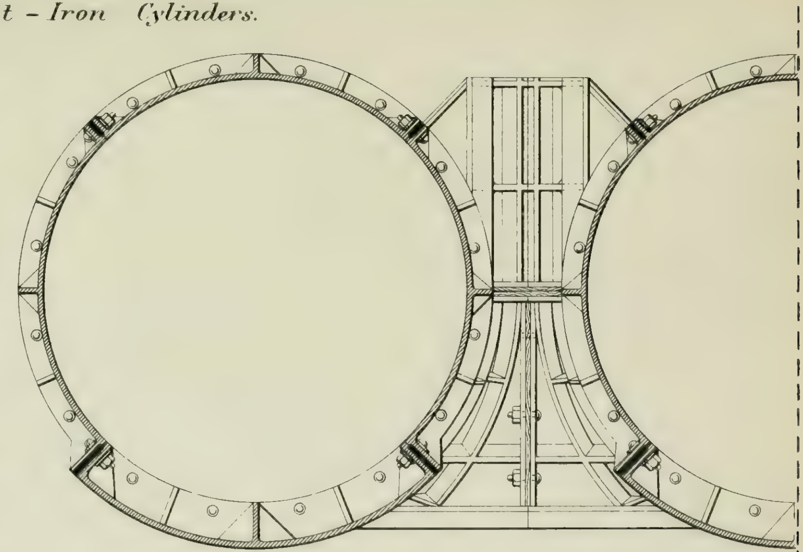


Fig. 14. *Transverse Section.*

Scale 1/48th.

Inches 12 0 1 2 3 4 5 6 7 8 9 10 Feet.

Mechanical Engineers 1894.

Plate 98.

MANCHESTER DRAINAGE WORKS.

Bridgewater Canal Crossing.

Cutwater.

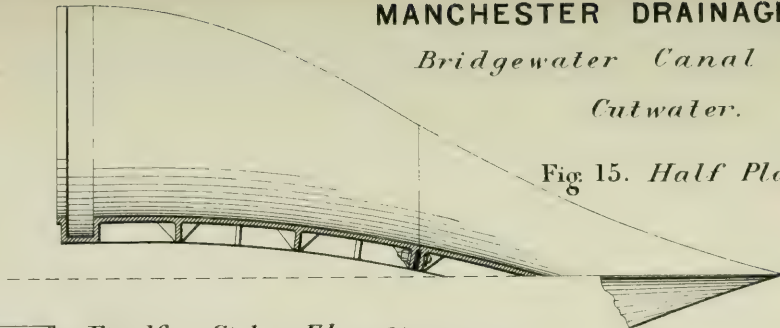


Fig. 15. *Half Plan.*

Fig. 16. *Side Elevation.*

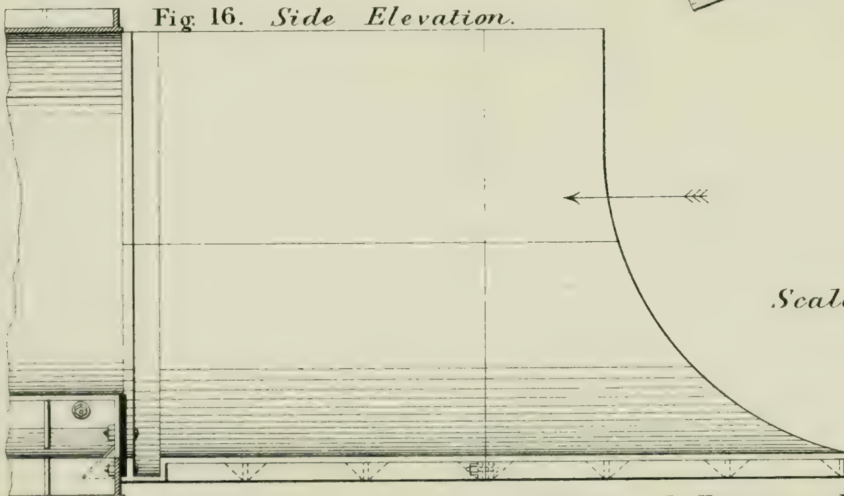
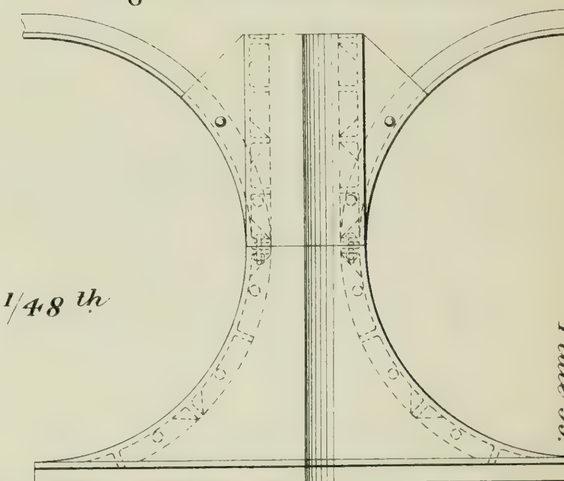


Fig. 17. *Front Elevation.*



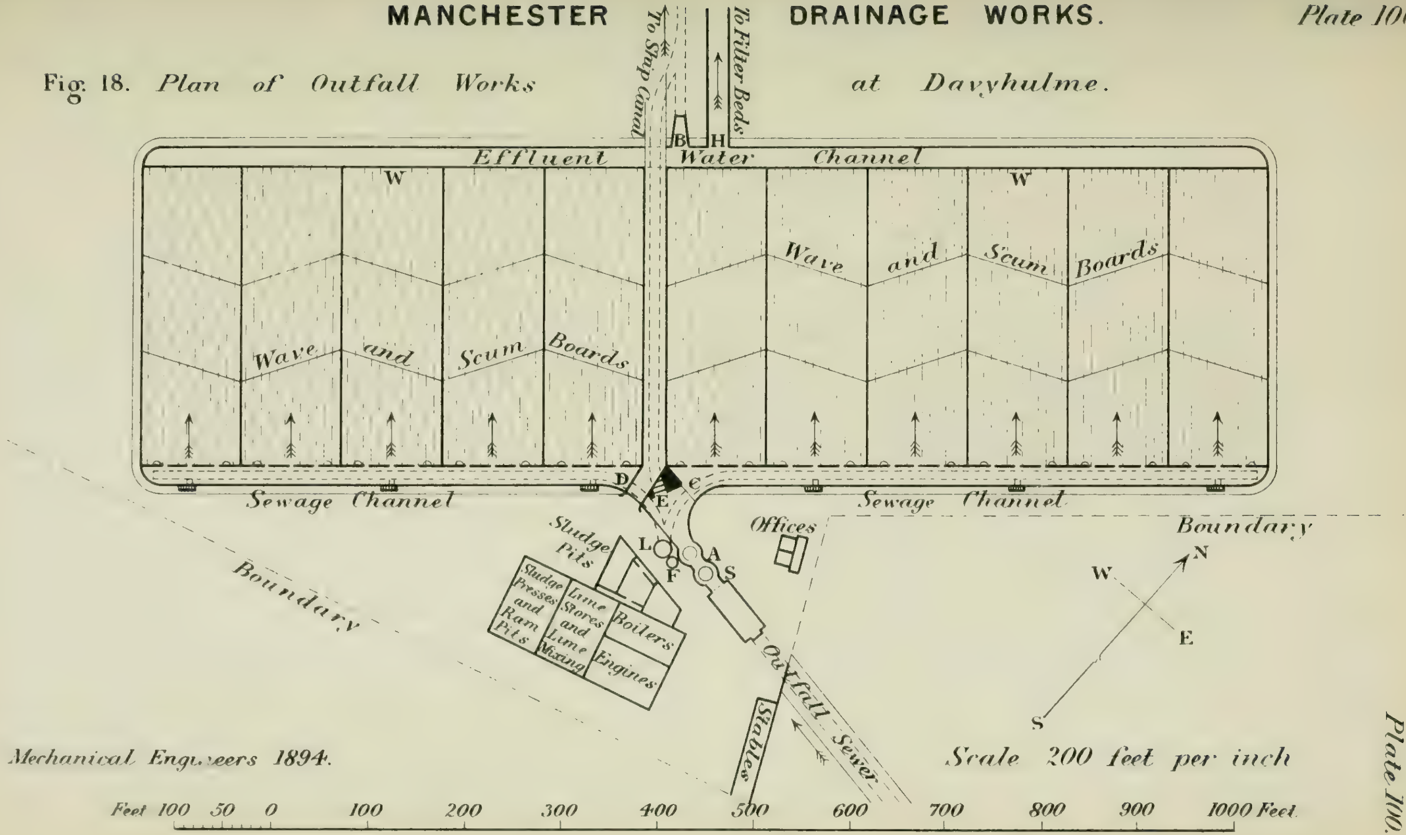
Scale 1/48 th.

Mechanical Engineers 1894.

Plate 99.

MANCHESTER DRAINAGE WORKS.

Fig. 18. *Plan of Outfall Works at Davyhulme.*

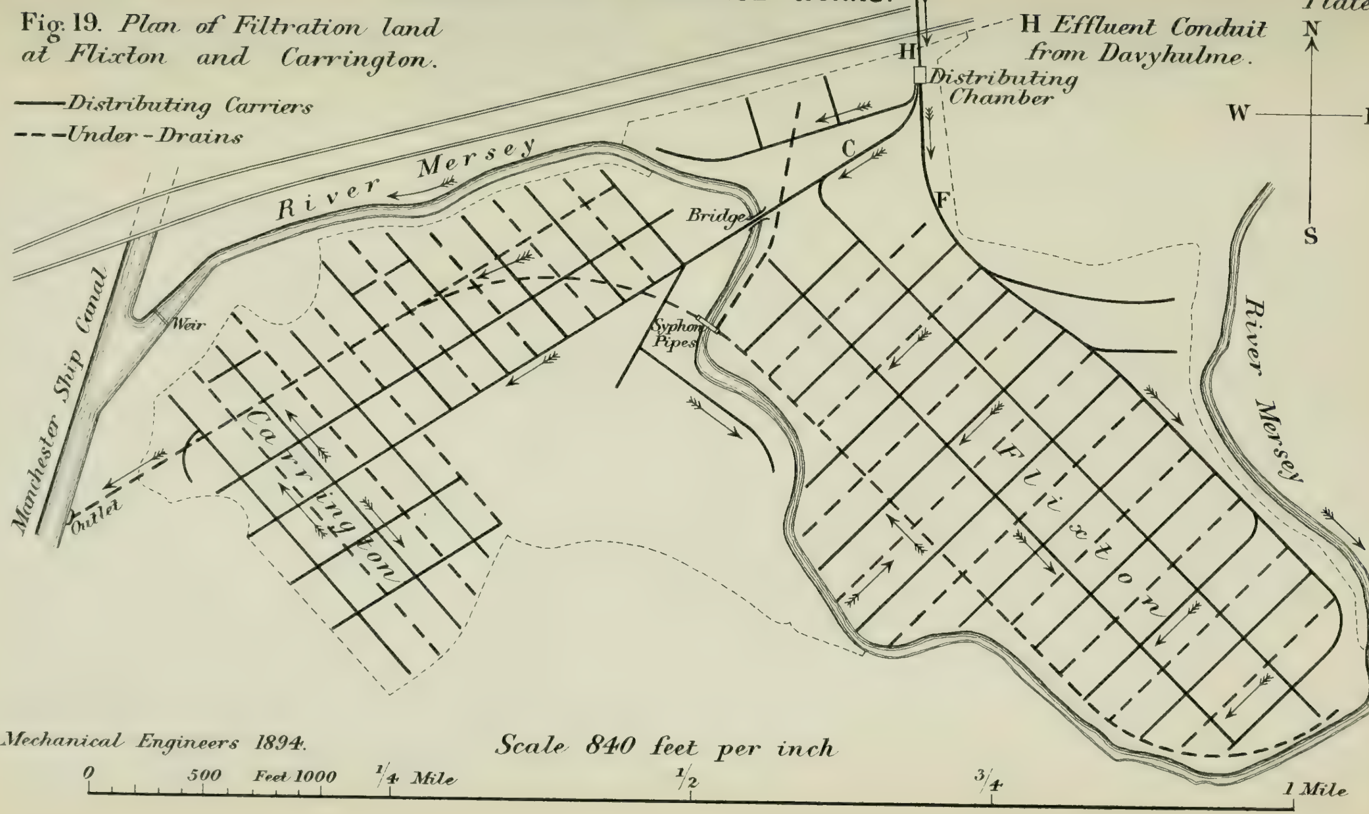


Mechanical Engineers 1894.

Plate 100.

MANCHESTER DRAINAGE WORKS.

Fig. 19. *Plan of Filtration land at Flixton and Carrington.*



Mechanical Engineers 1894.

Plate 101.

Fig. 20. *Sludge Press.*

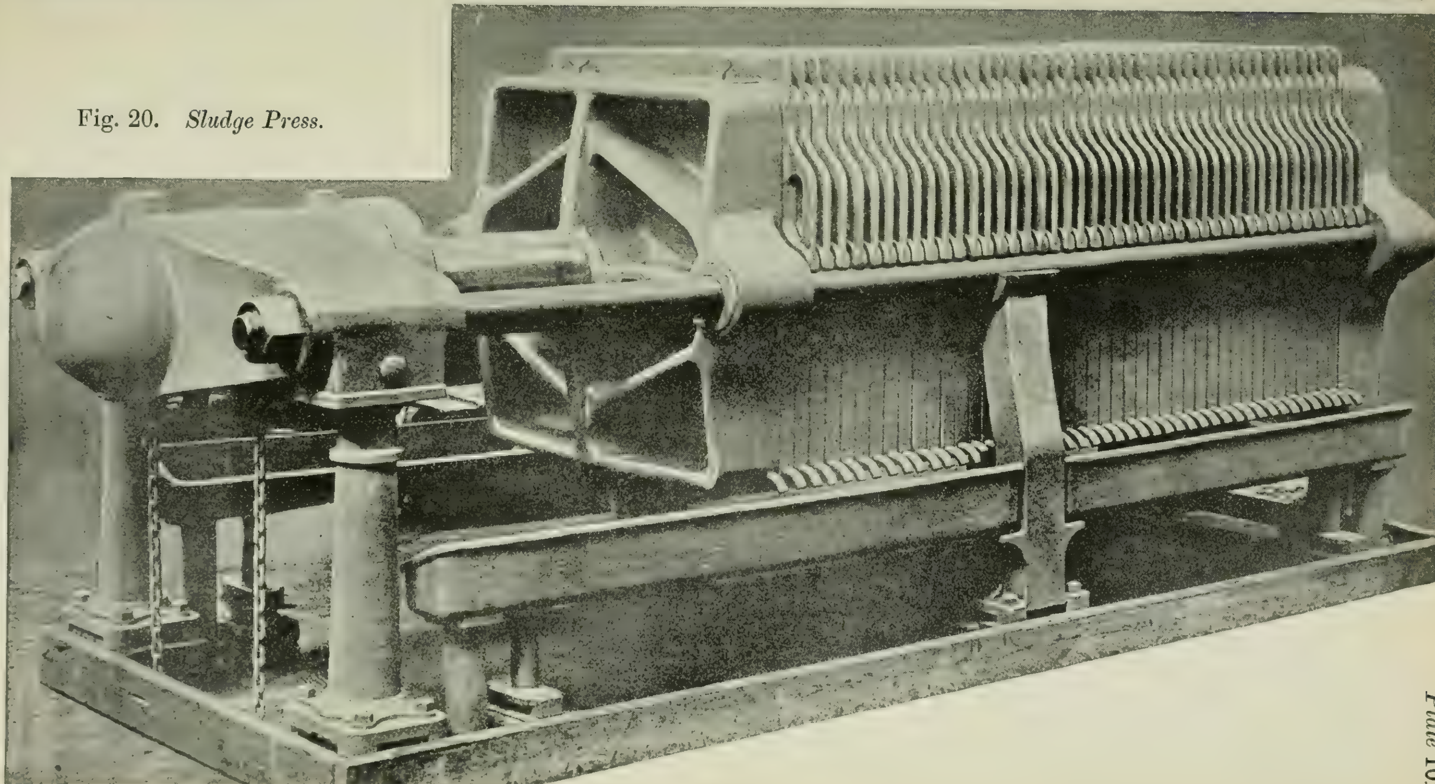


Plate 102.

Fig. 21. *Sludge Press.*

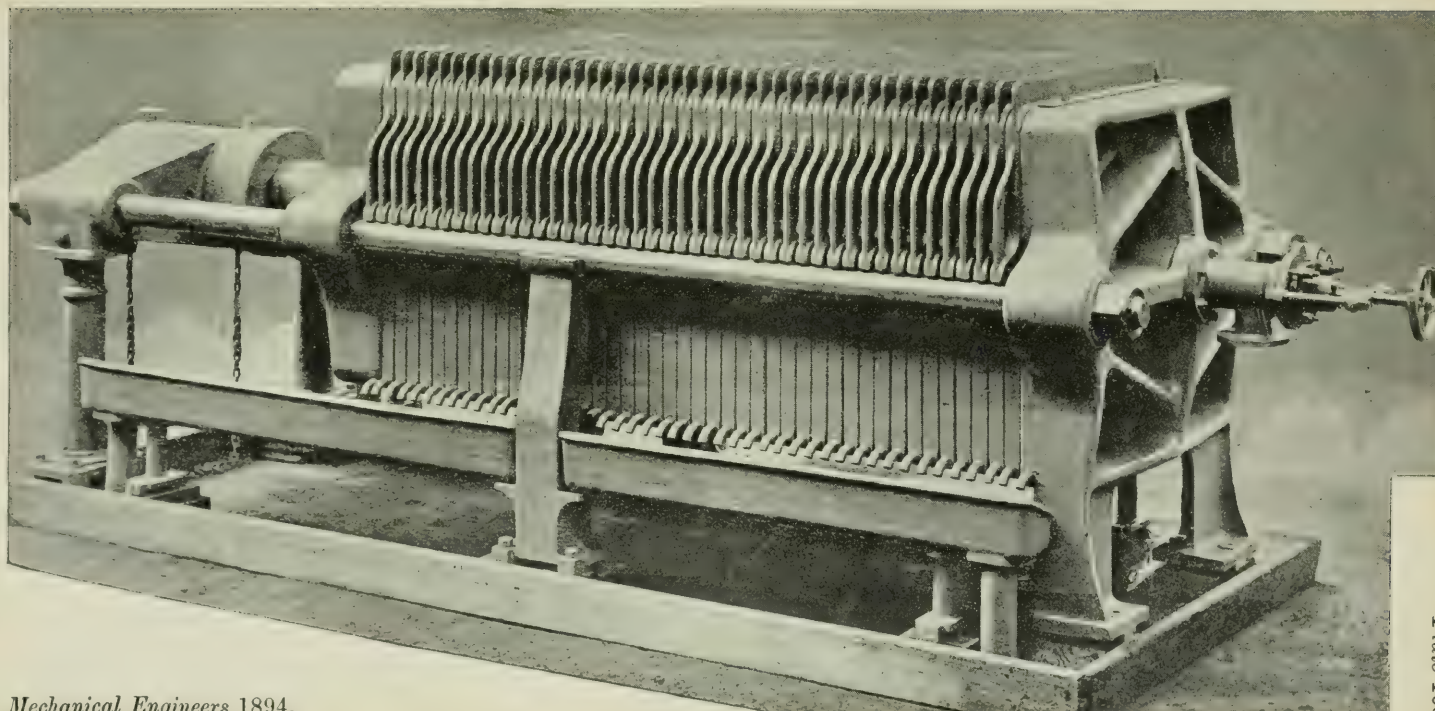
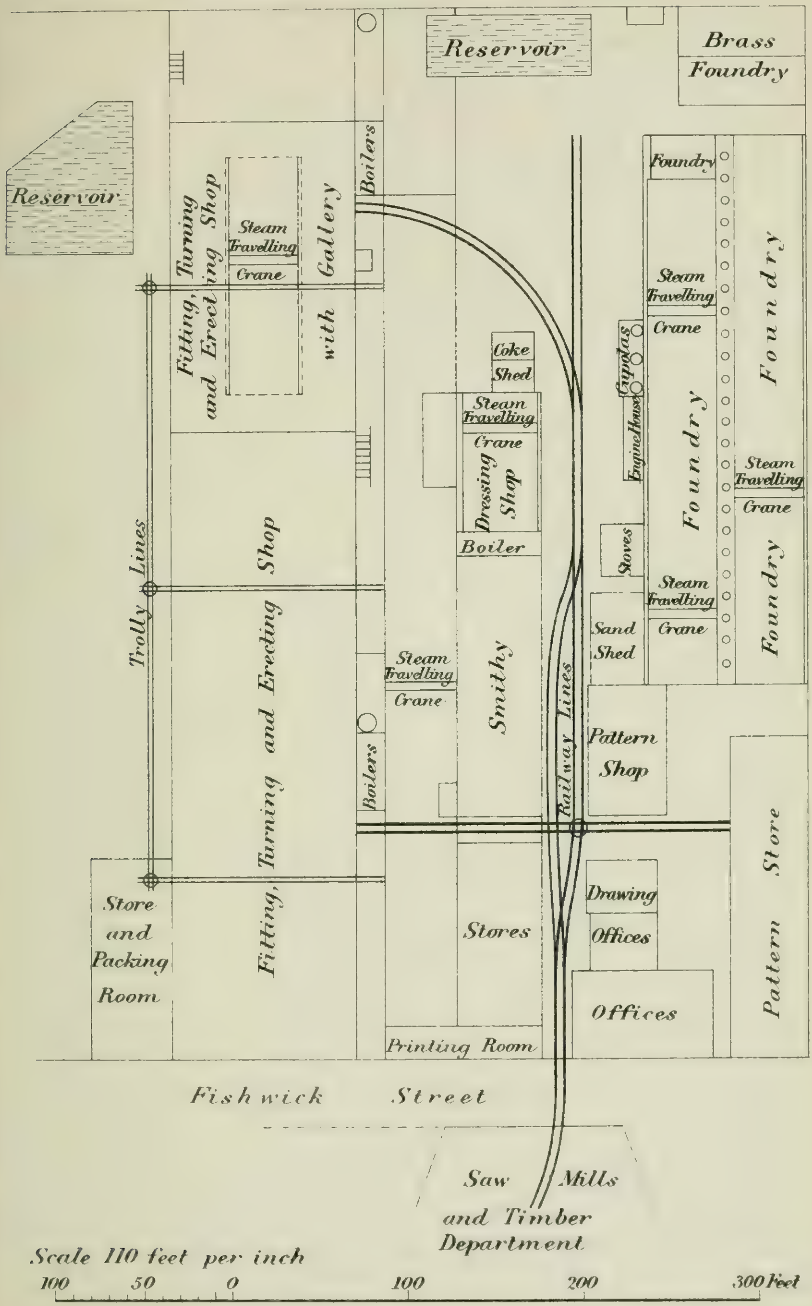


Plate 103.

ROCHDALE.

Messrs. Thomas Robinson and Son's Works.



HORWICH WORKS.

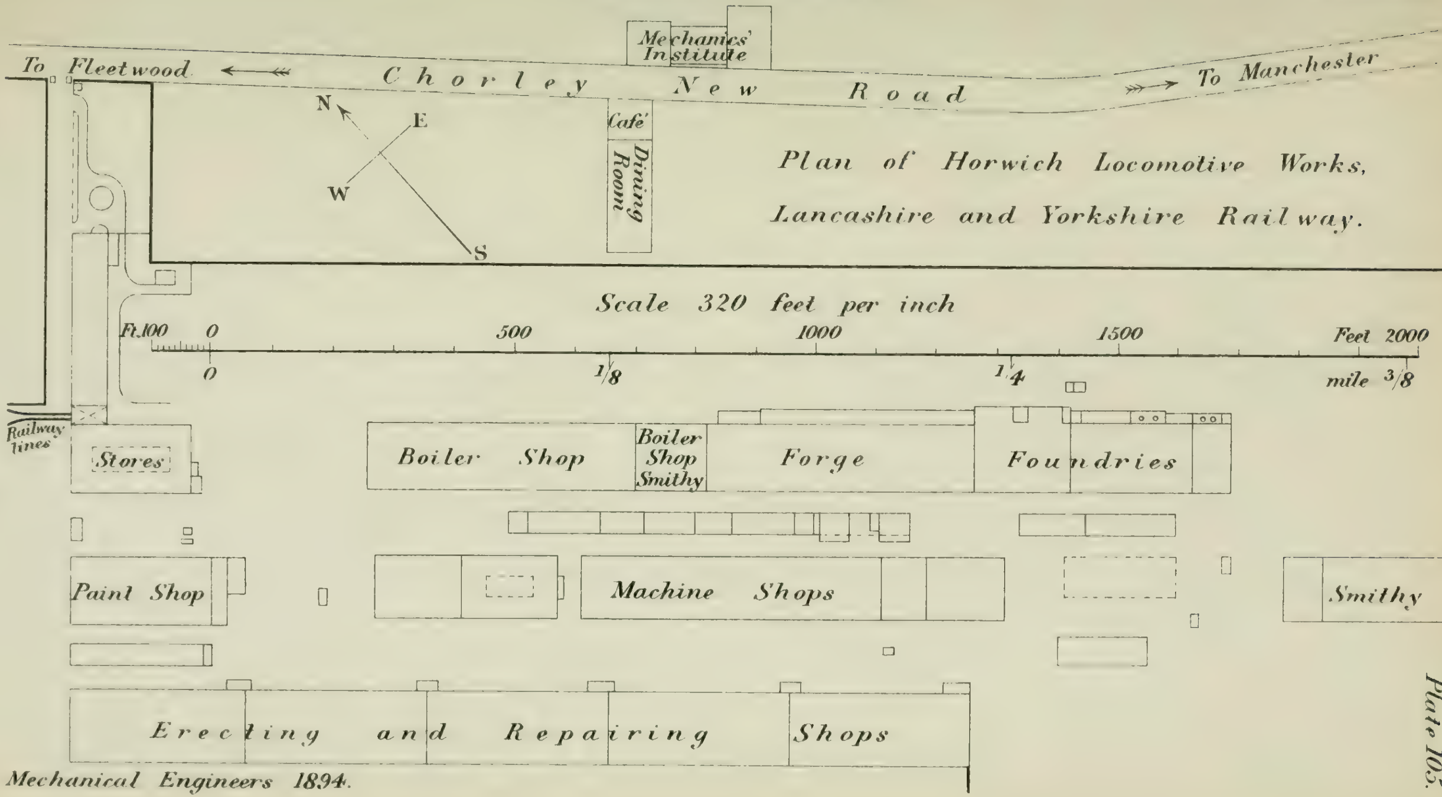
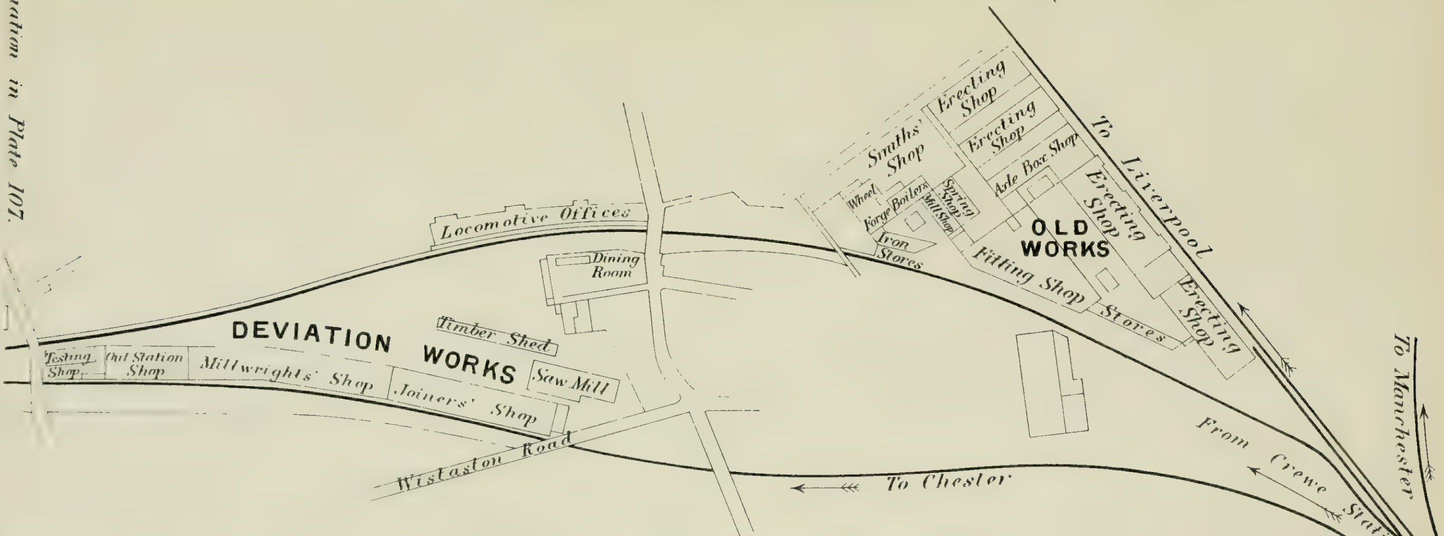


Plate 105.

CREWE WORKS.

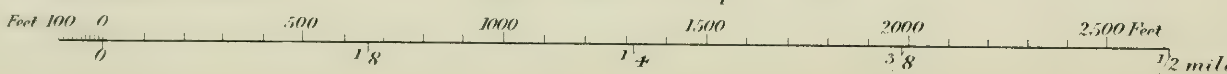
Half Plan of Crewe Works,
London and North Western Railway.

See continuation in Plate 107.



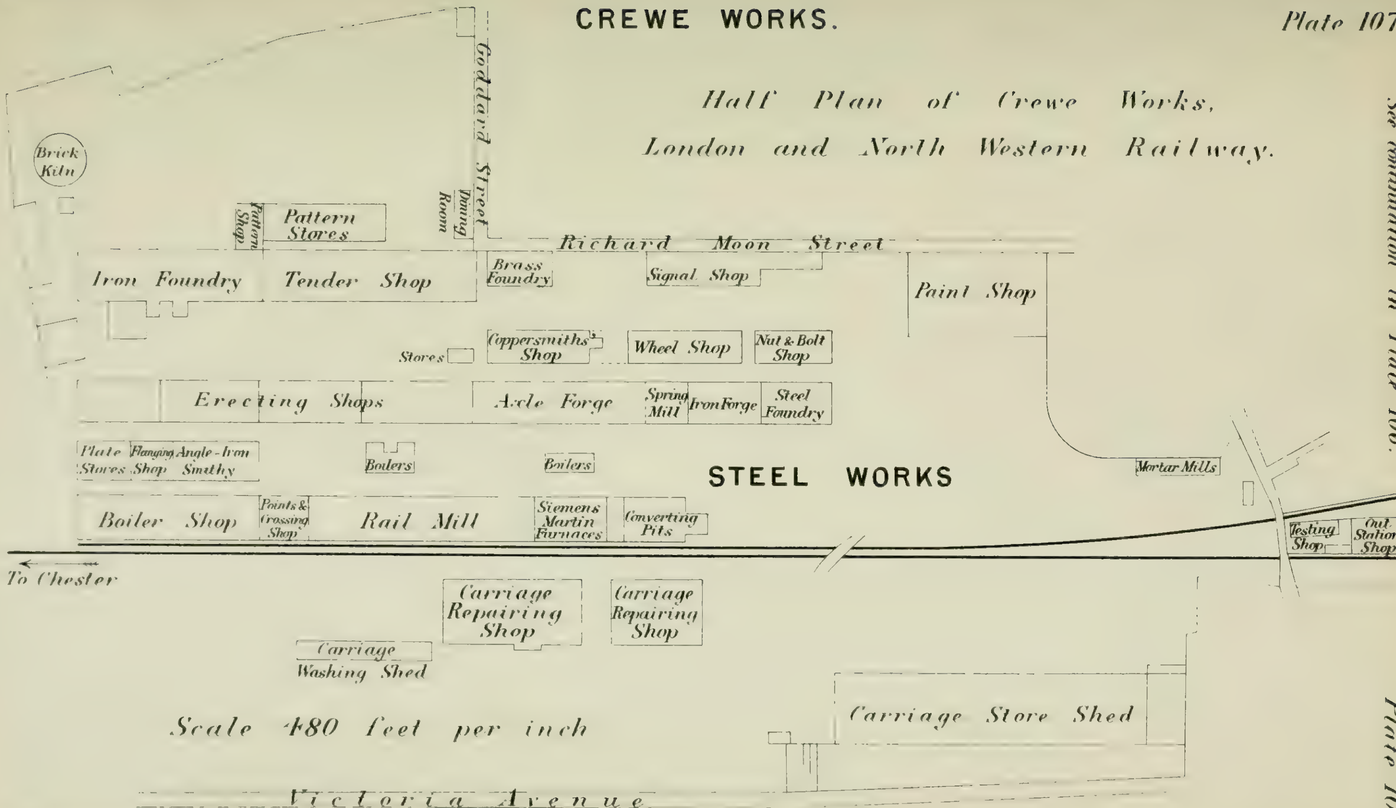
Mechanical Engineers 1894

Scale 480 feet per inch



CREWE WORKS.

Half Plan of Crewe Works, London and North Western Railway.



Scale 480 feet per inch

See continuation in Plate 106.

Plate 107.

WATCH SCREWS.

Automatic Screw-making Machine.

Fig. 1. Front Elevation.

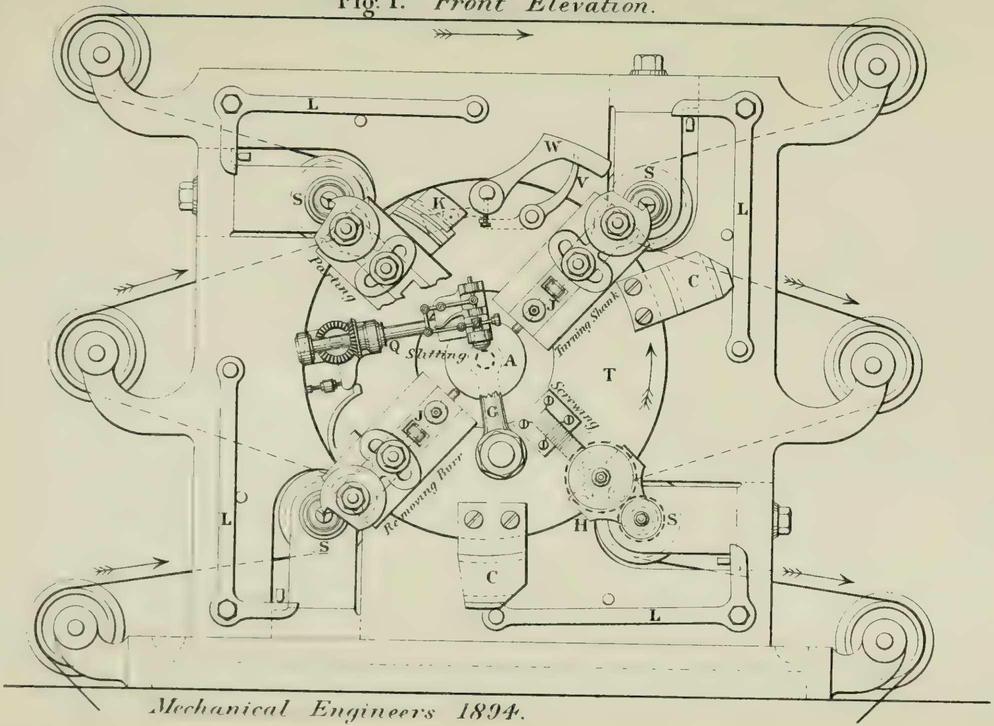
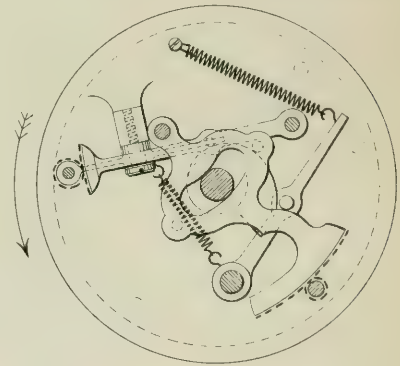


Fig. 2. Face View of Racks and Levers.

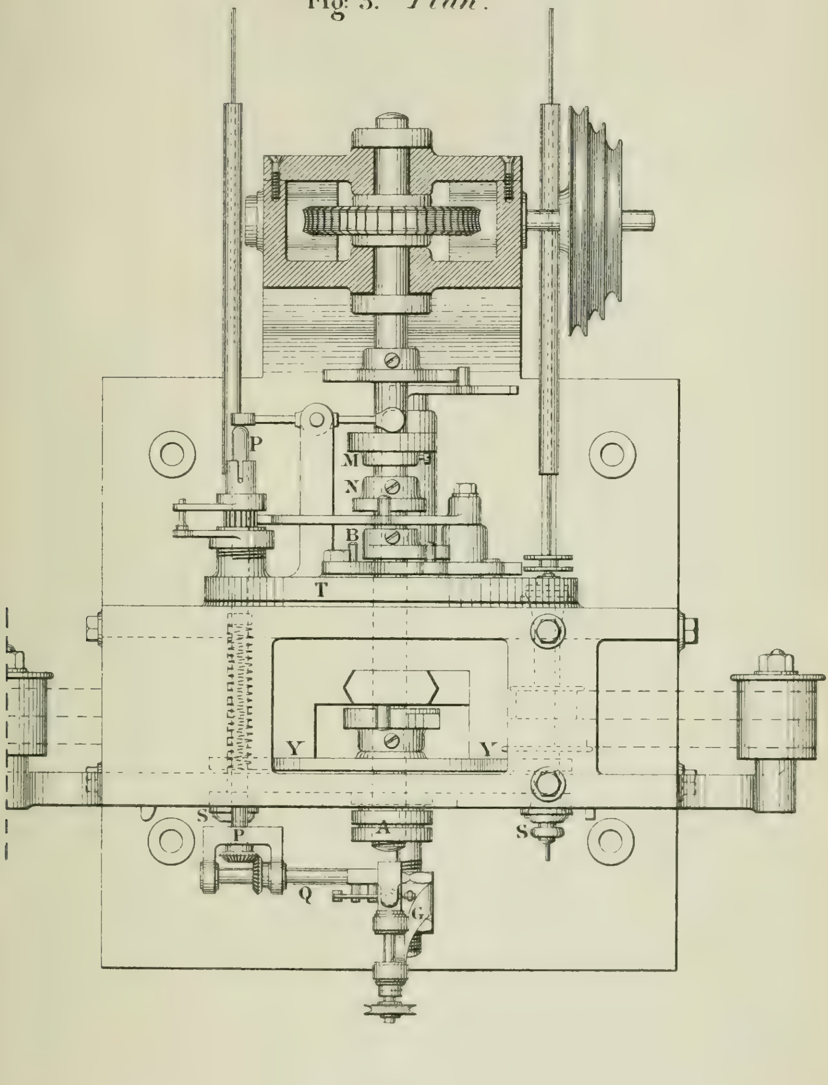


Scale 1/4 th.

Plate 108.

Automatic Screw-making Machine.

Fig: 3. *Plan.*



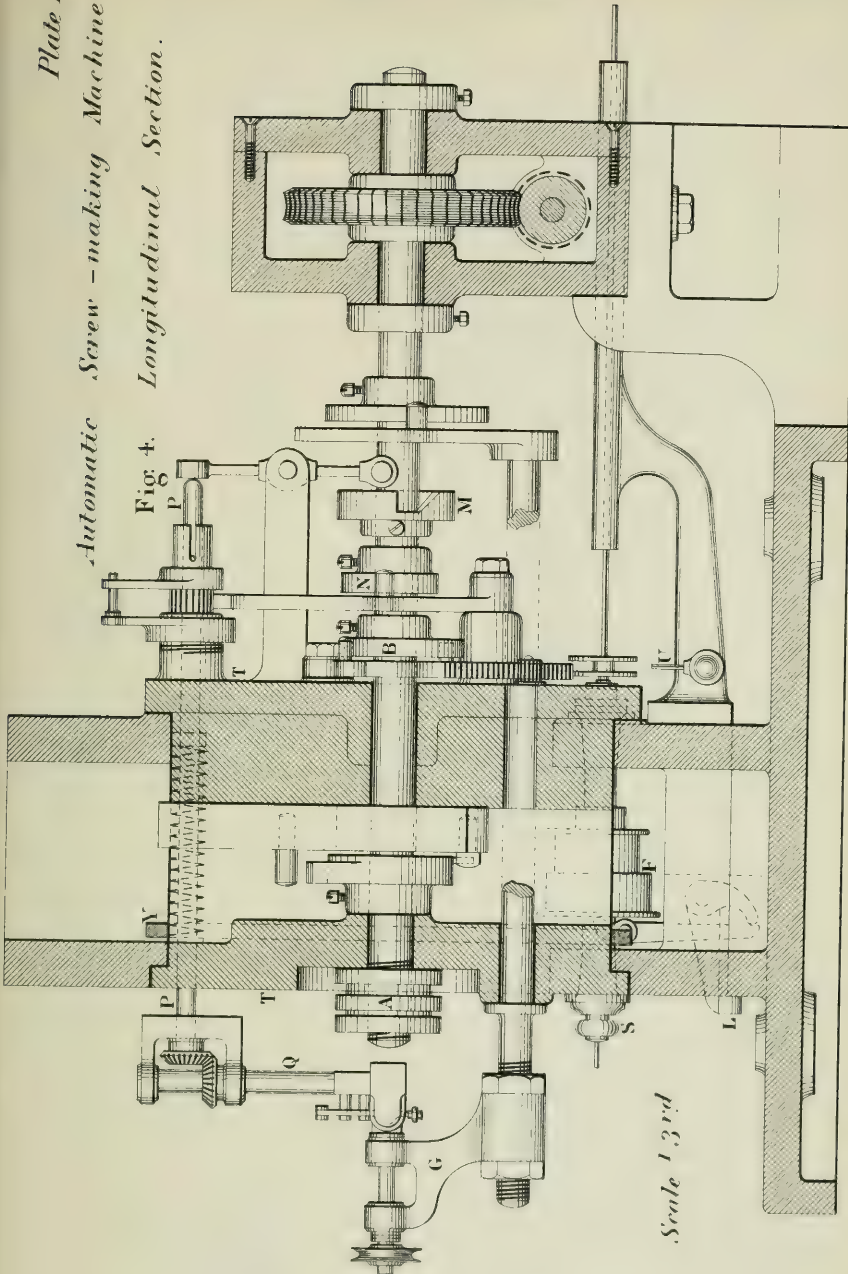
Scale 1/4th

Plate 110.

Automatic Screw-making Machine.

Longitudinal Section.

Fig. 4.



Scale 1/3rd

WATCH SCREWS.

Fig: 5. *Standard Watch Screws, enlarged to ten times full size.*

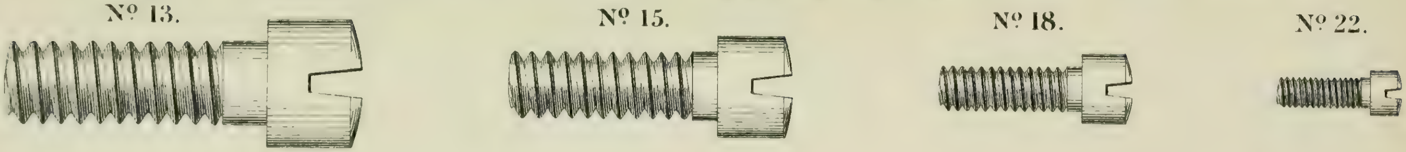


Fig: 6. *Longitudinal Section of hollow Lathe-Spindle, full size.*

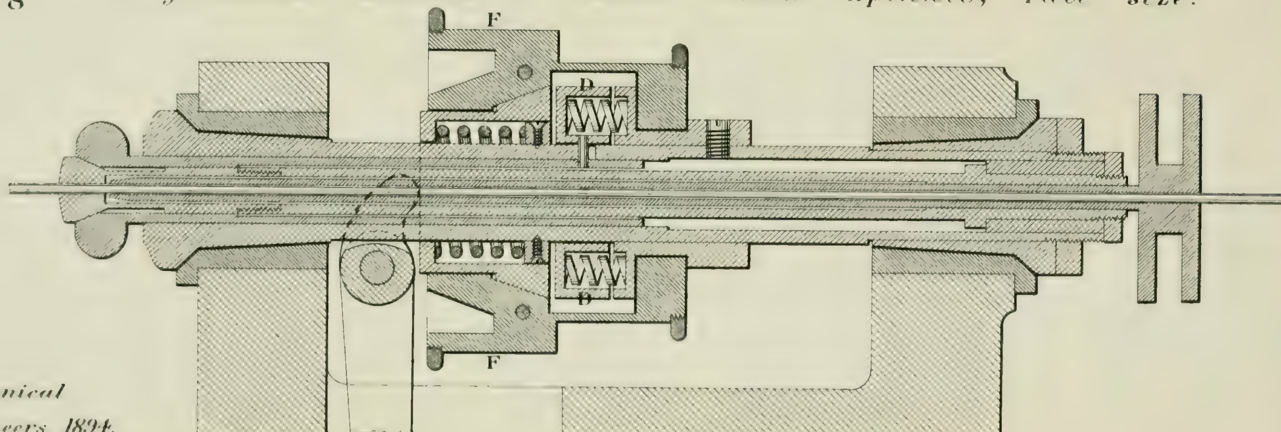
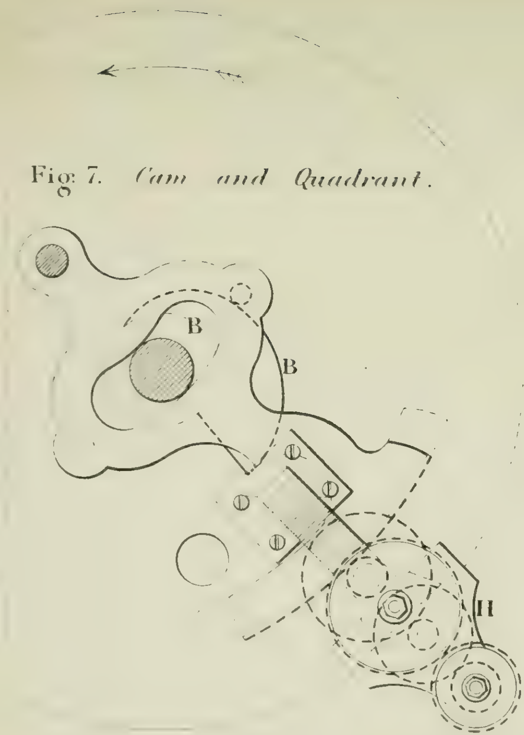


Plate III.

WATCH SCREWS.

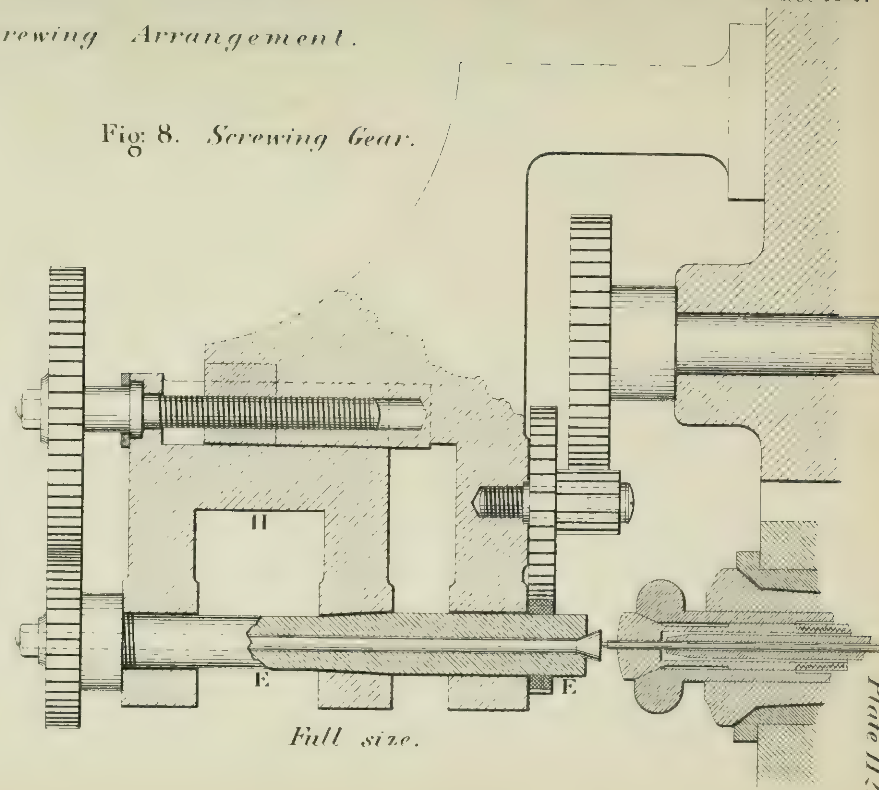
Screwing Arrangement.

Fig: 7. *Cam and Quadrant.*



Half full size.

Fig: 8. *Screwing Gear.*



Full size.

Plate 112.

WATCH SCREWS.

*Slitting - Saw
and
Quadrantal
Carrier.*

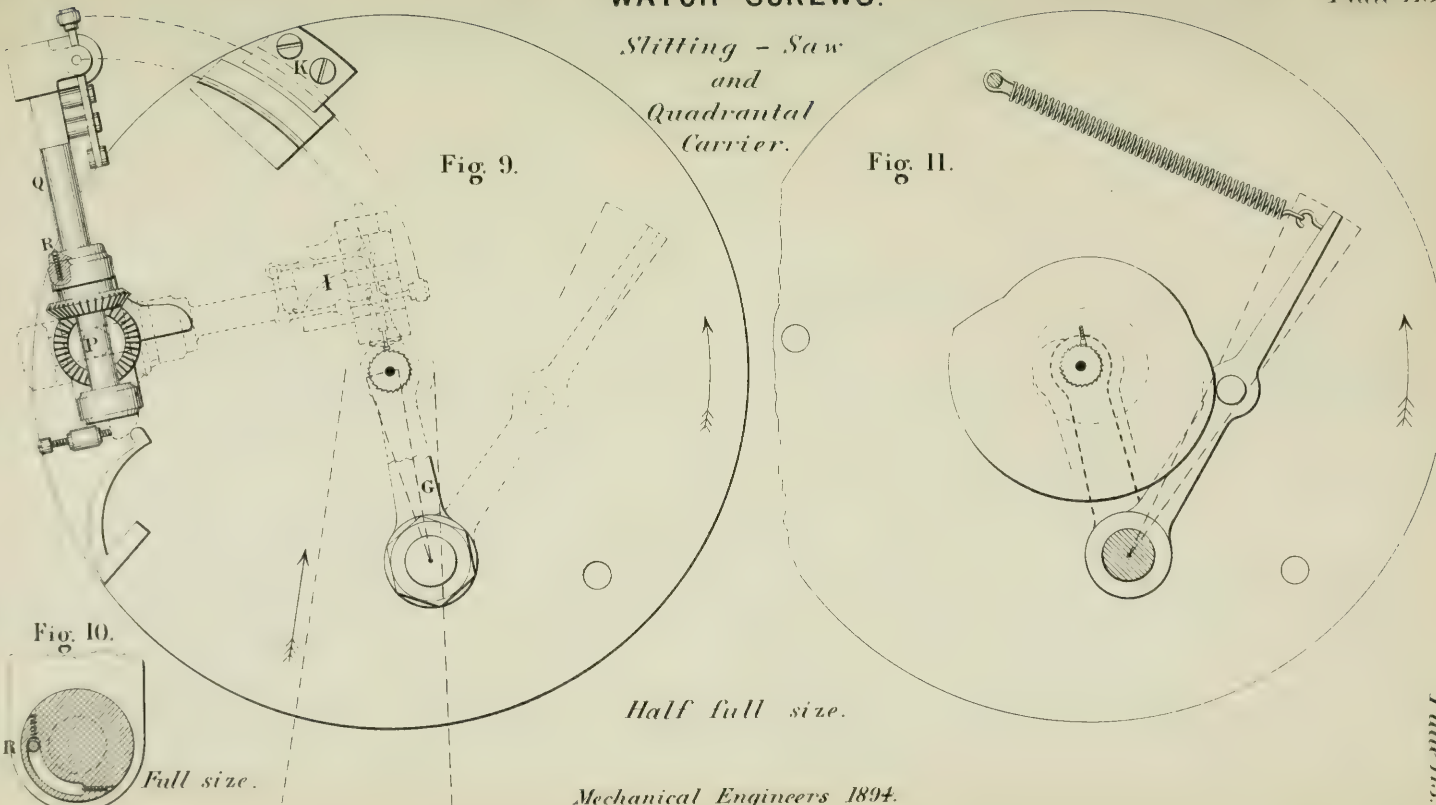


Fig. 9.

Fig. 10.

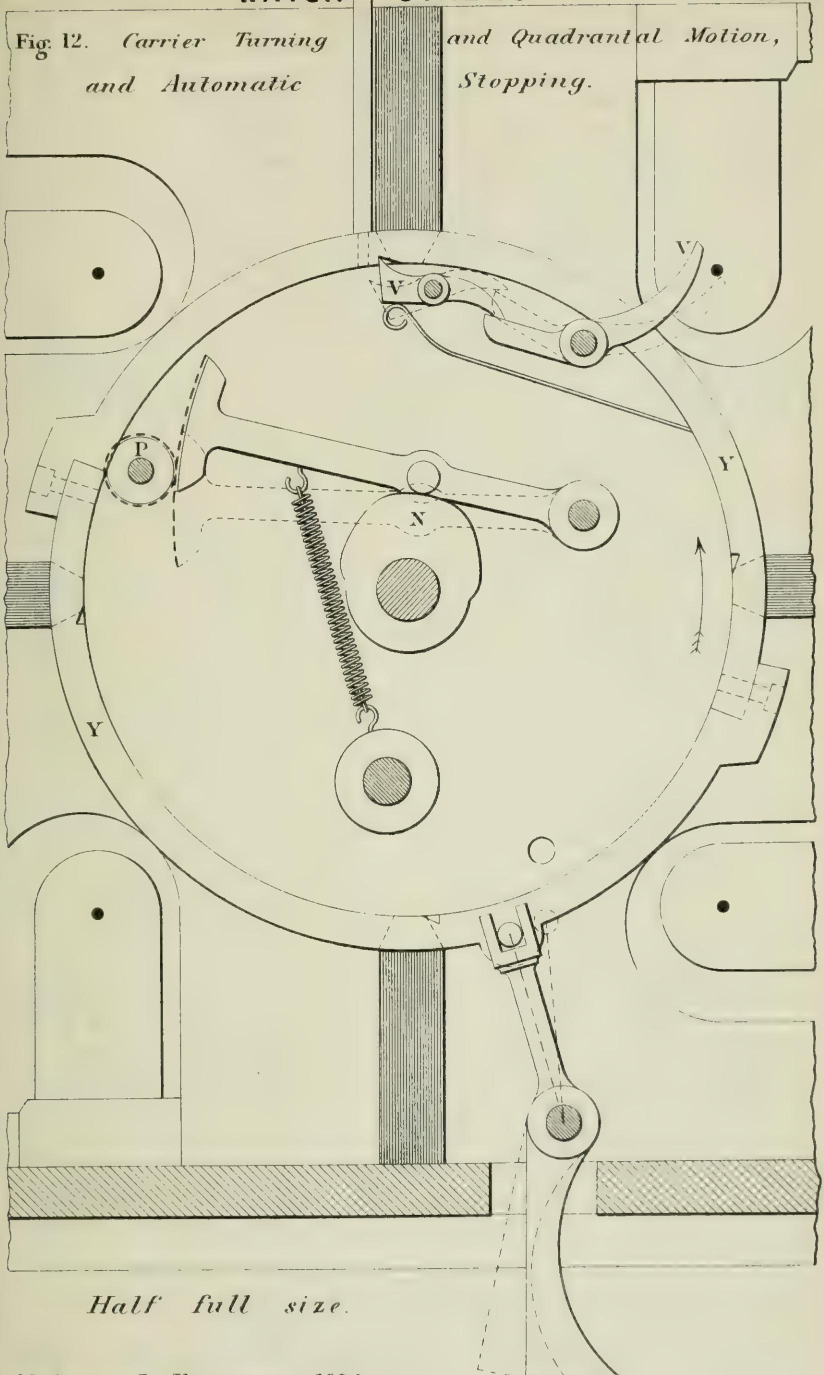
Full size.

Fig. 11.

Half full size.

Plate 113.

Fig. 12. *Carrier Turning and Quadrantal Motion, and Automatic Stopping.*



Half full size.

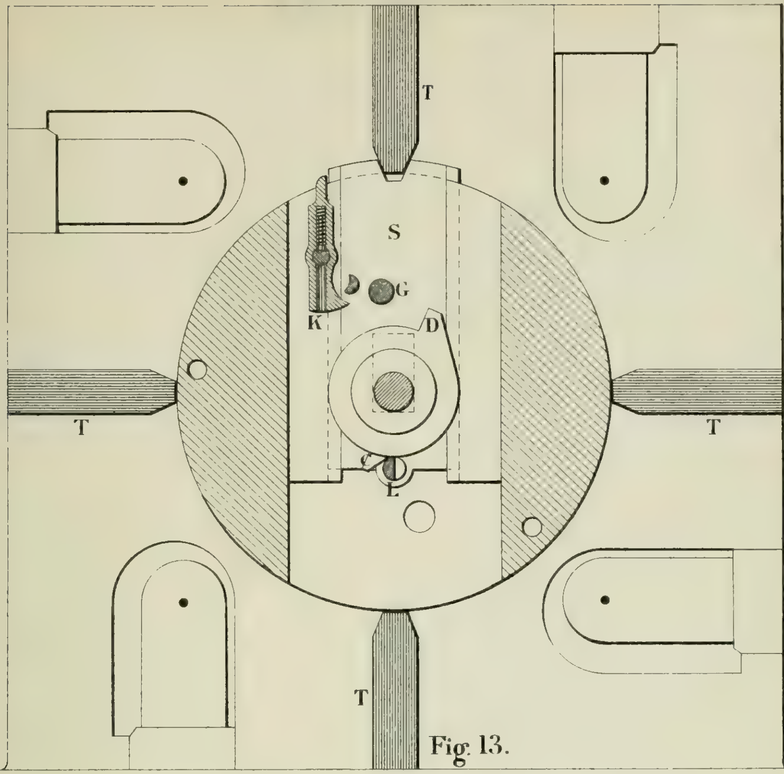


Fig. 13.

Rotation and Locking of Turret.

Scale 1/3rd.

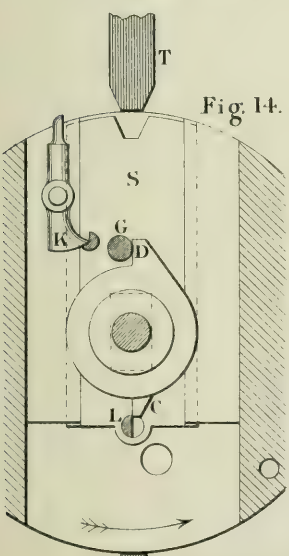


Fig. 14.

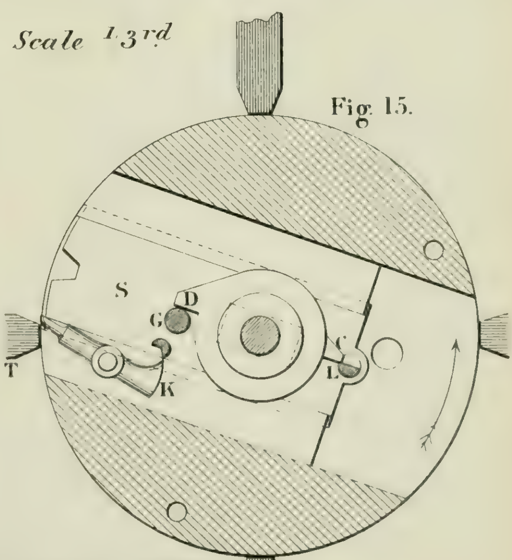


Fig. 15.

Fig. 16. *Section of British Association Thread.*

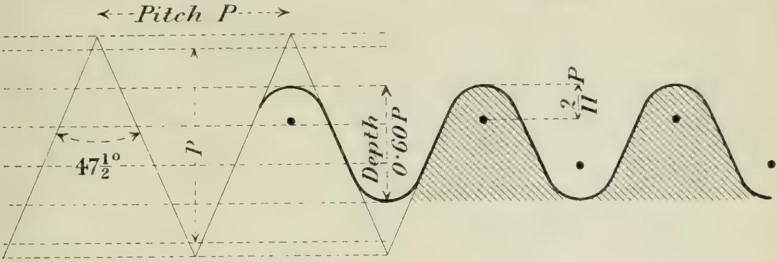


Fig. 17. *Modified Section of British Association Thread, ascending series.*

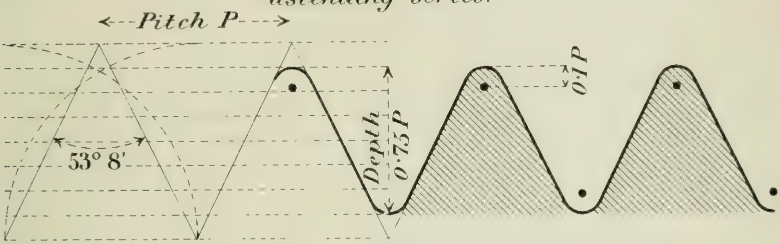
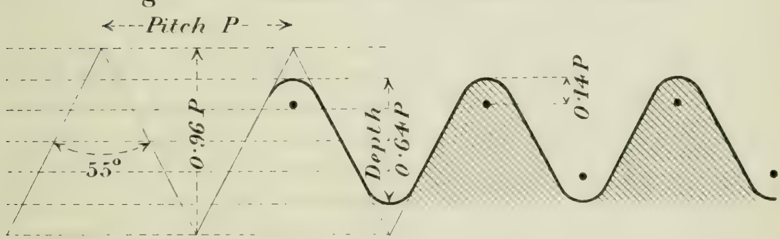
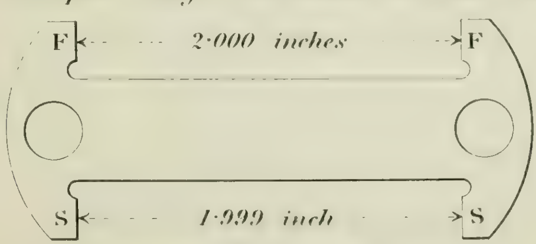


Fig. 18. *Section of Whitworth Thread.*



Double Calliper Gauge for Screws of lens fittings.

Fig. 19.



Full size.

Mechanical Engineers 1894.

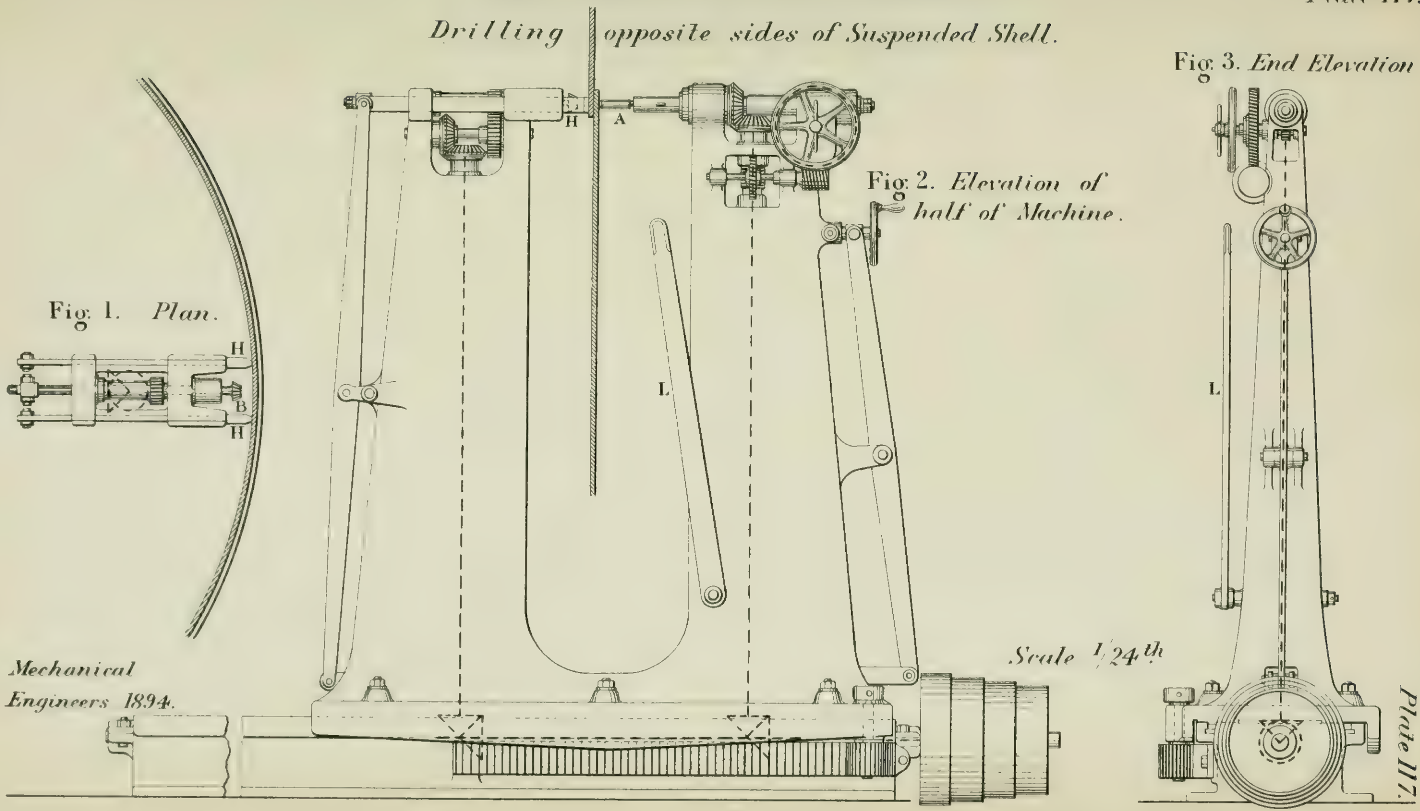
BOILER-SHELL DRILLING MACHINES.

Drilling opposite sides of Suspended Shell.

Fig. 1. *Plan.*

Fig. 2. *Elevation of half of Machine.*

Fig. 3. *End Elevation.*



Scale 1/24th.

BOILER-SHELL DRILLING MACHINES.

Sliding Drill-Standards.

Fig. 4.

Elevation.

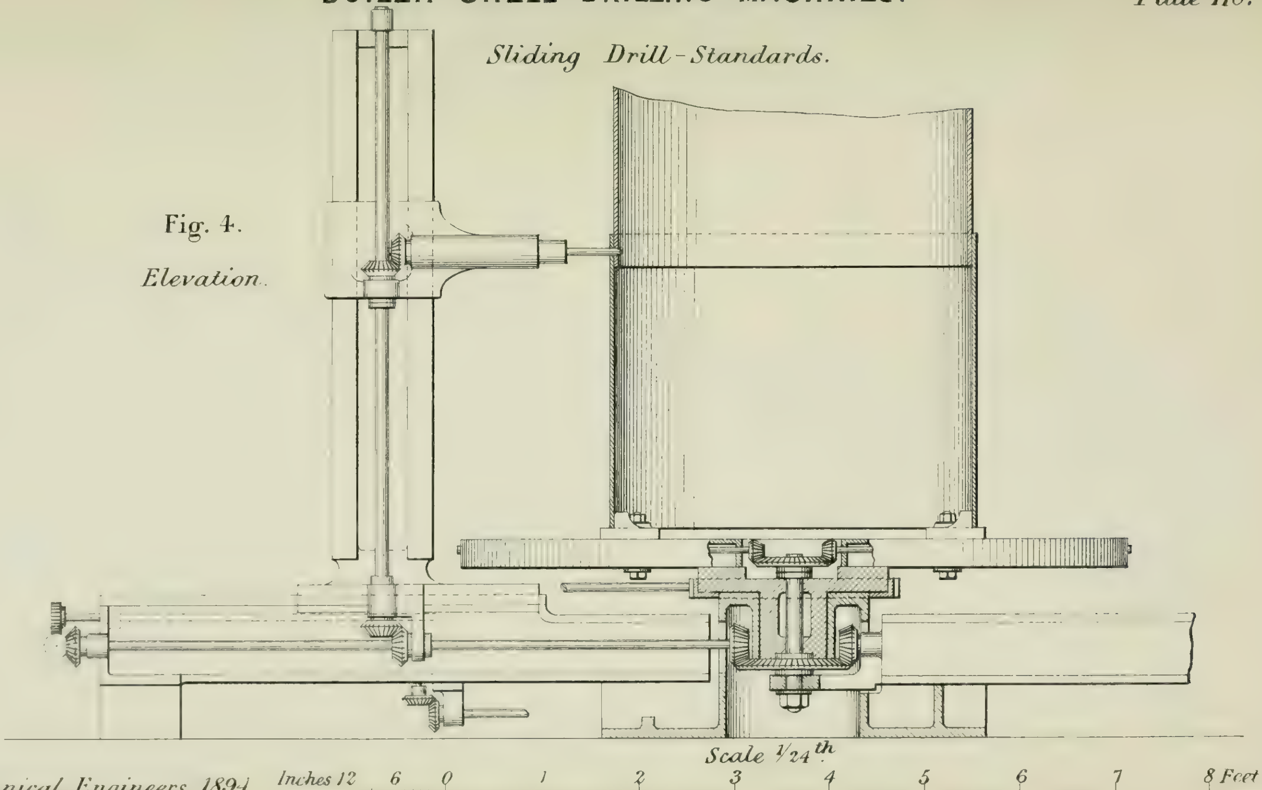


Plate 118.

BOILER-SHELL DRILLING MACHINES.

Plate 119.

Sliding Drills on Fixed Standards.

Fig. 5. *Sectional Elevation.*

Fig. 6. *End Elevation.*

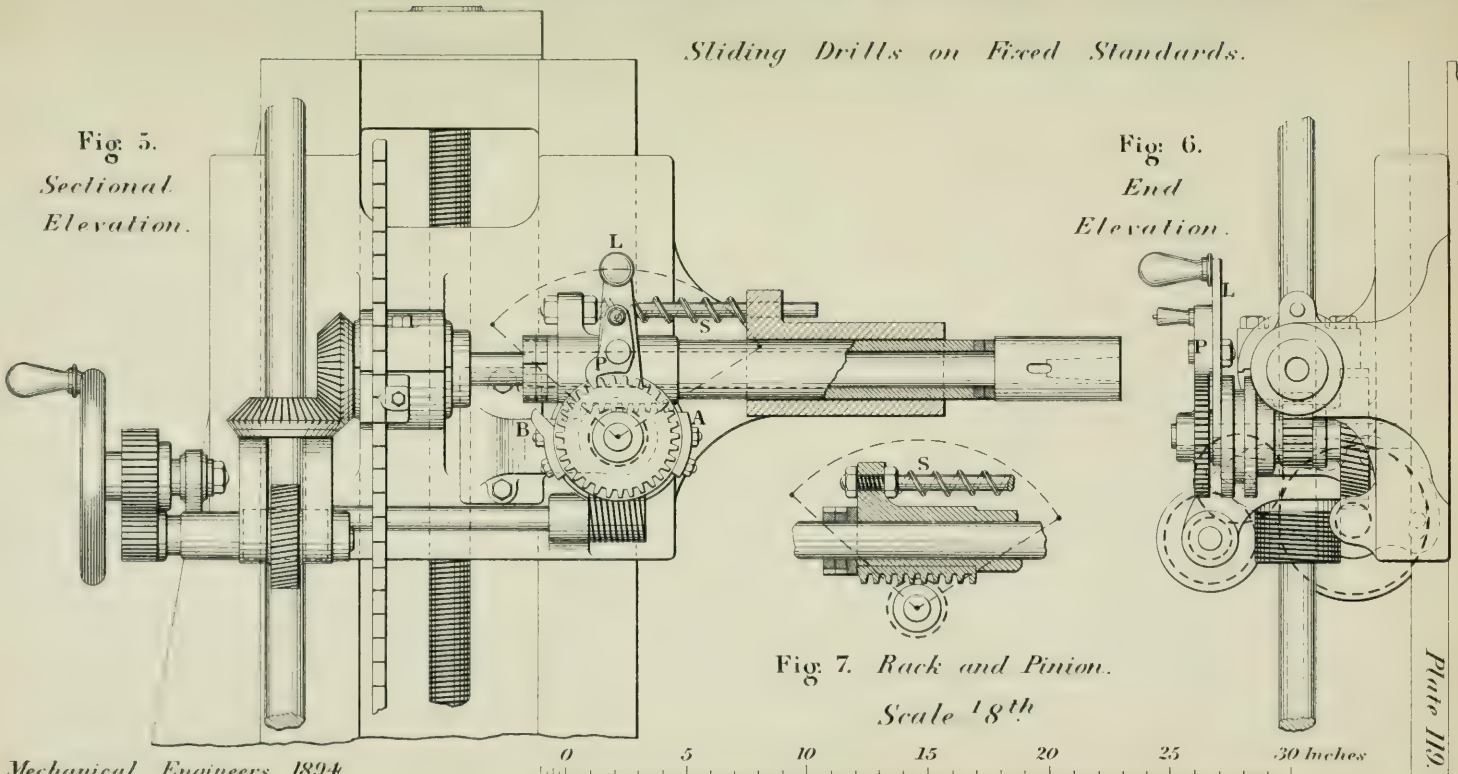


Fig. 7. *Rack and Pinion.*

Scale 1/8th.

Plate 120.

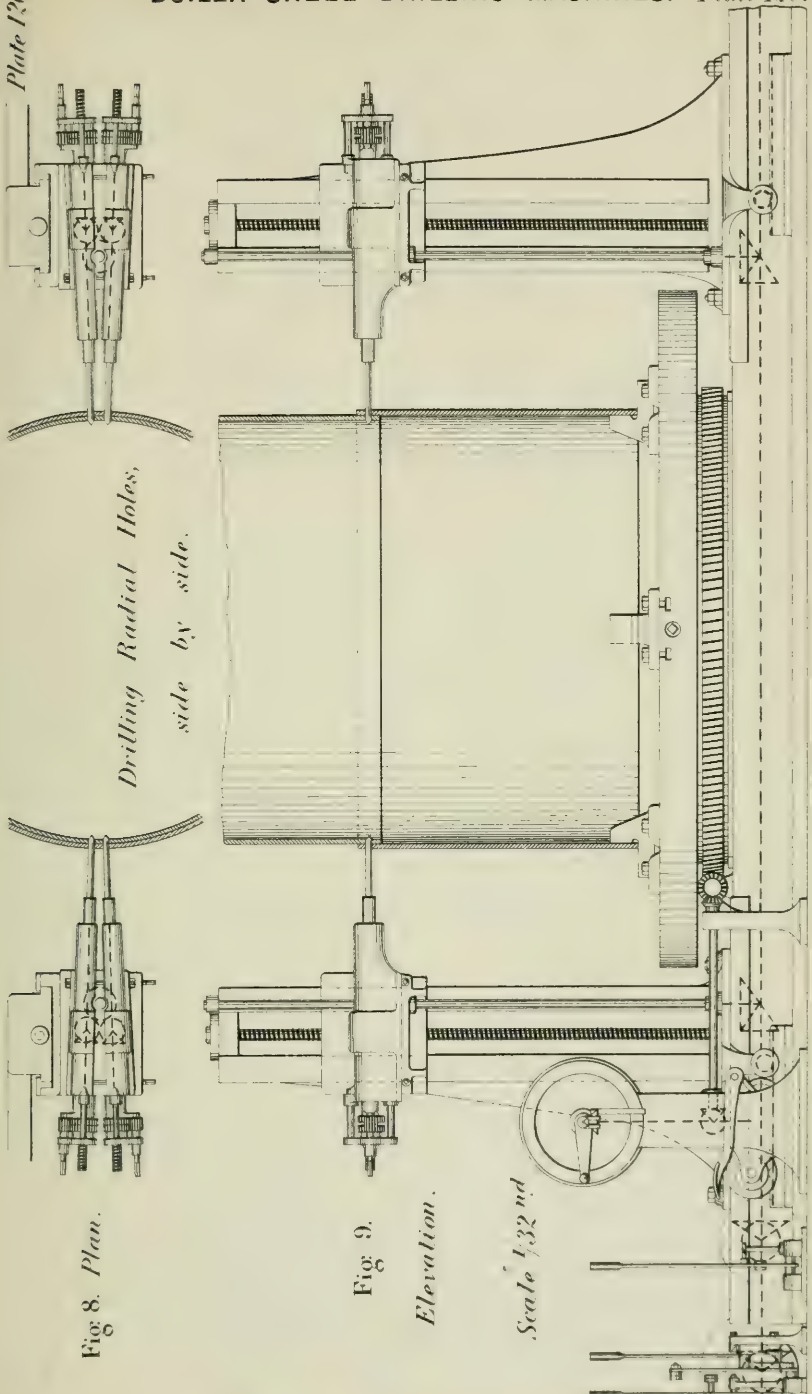


Fig. 8. Plan.

Fig. 9. Elevation.

Scale 1/32nd

BOILER-SHELL DRILLING MACHINES.

Drilling Head.

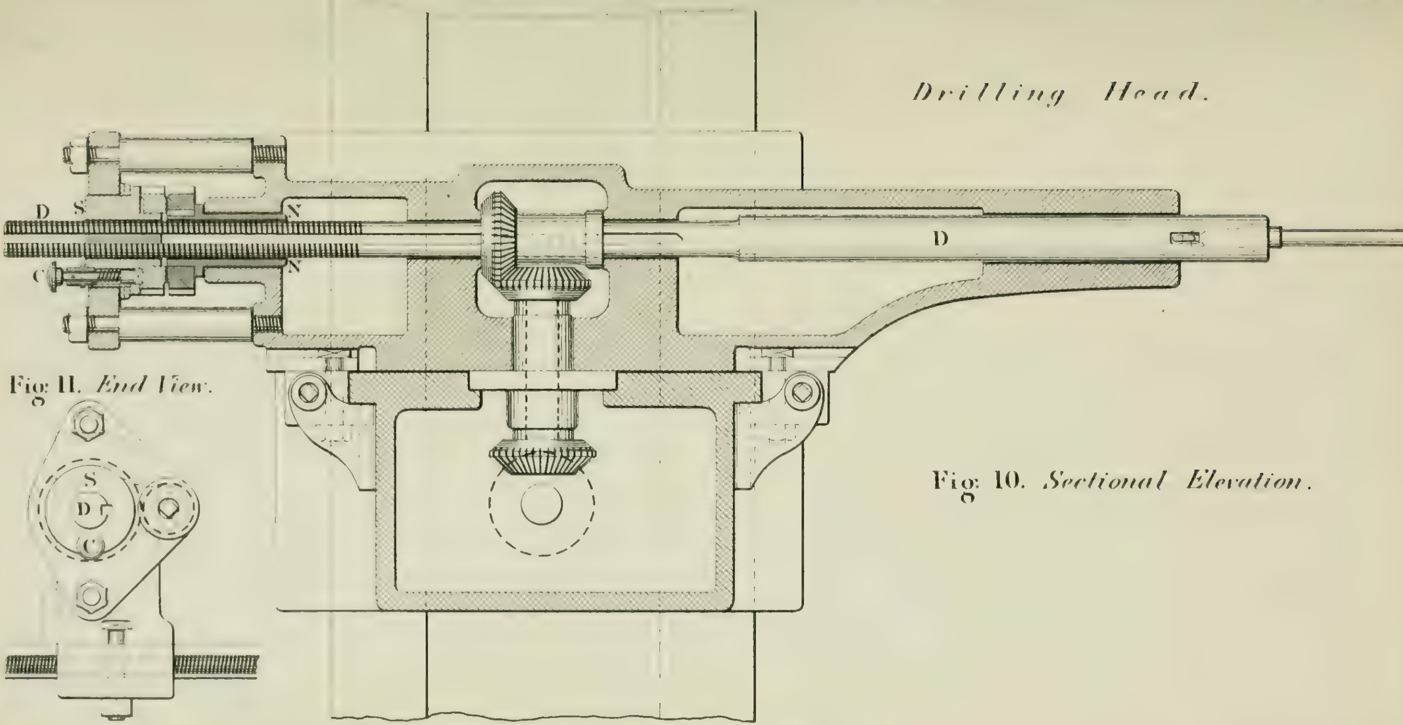
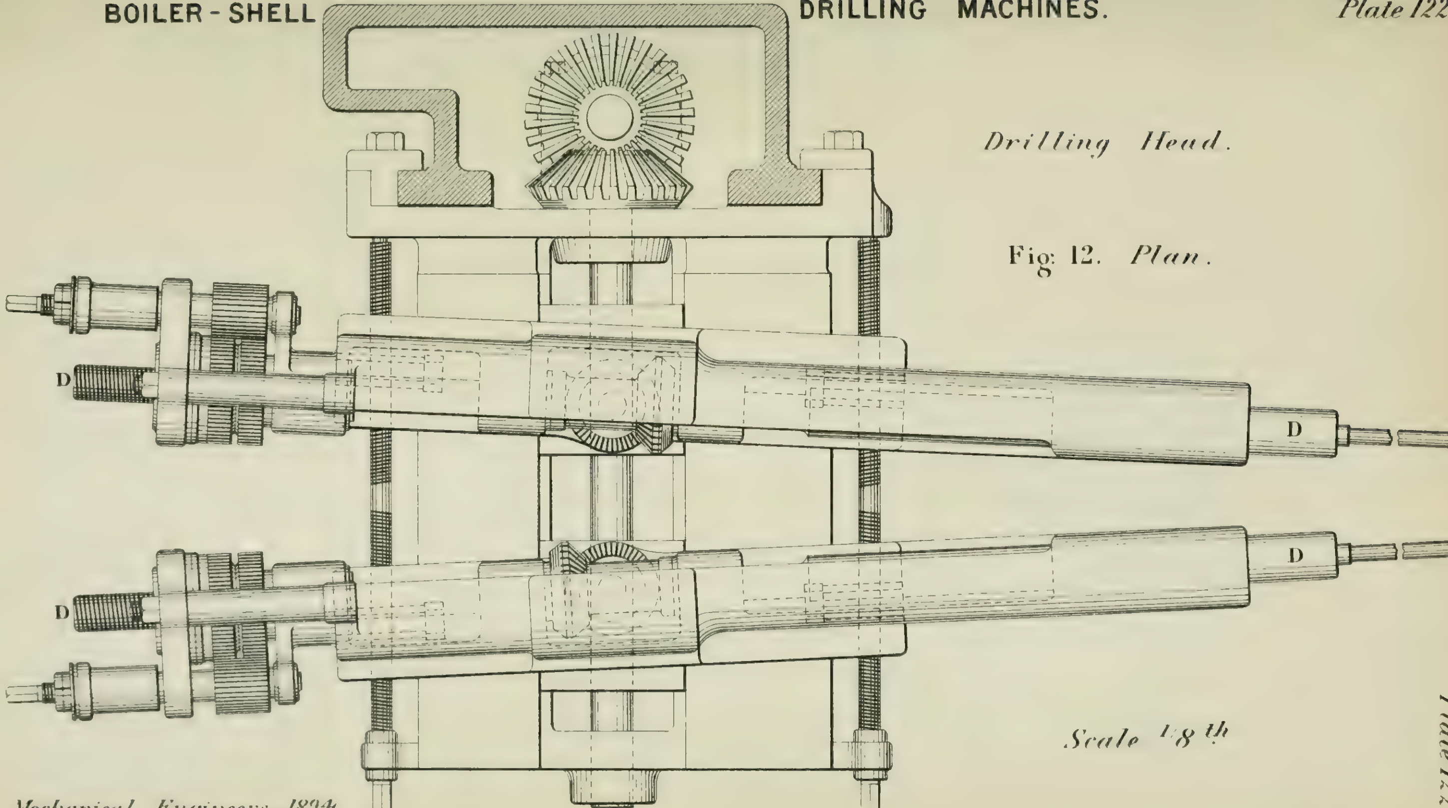


Fig. 10. *Sectional Elevation.*

Fig. 11. *End View.*

Scale 1/8th.

Plate 121.



Drilling Head.

Fig: 12. *Plan.*

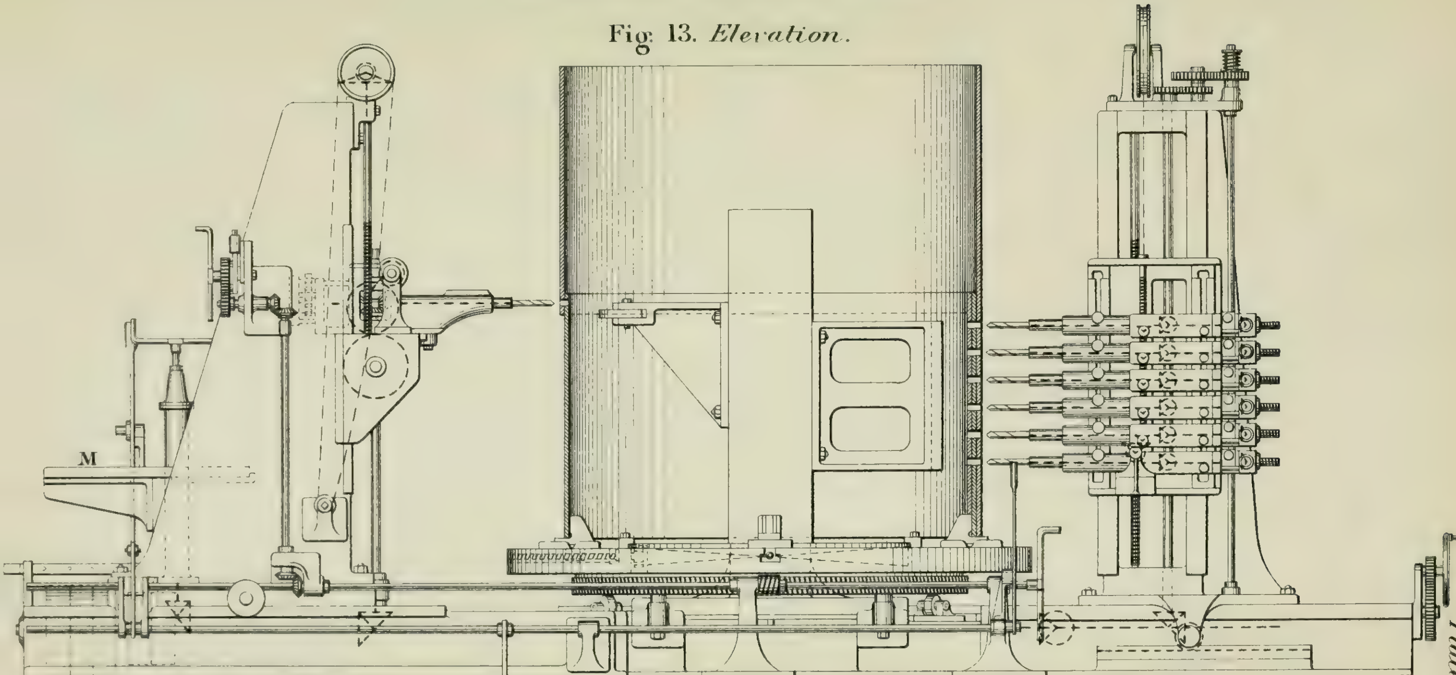
Scale 1/8th

Plate 122.

BOILER-SHELL DRILLING MACHINES.

Multiple Drilling Machine.

Fig. 13. *Elevation.*



Scale 1/40th

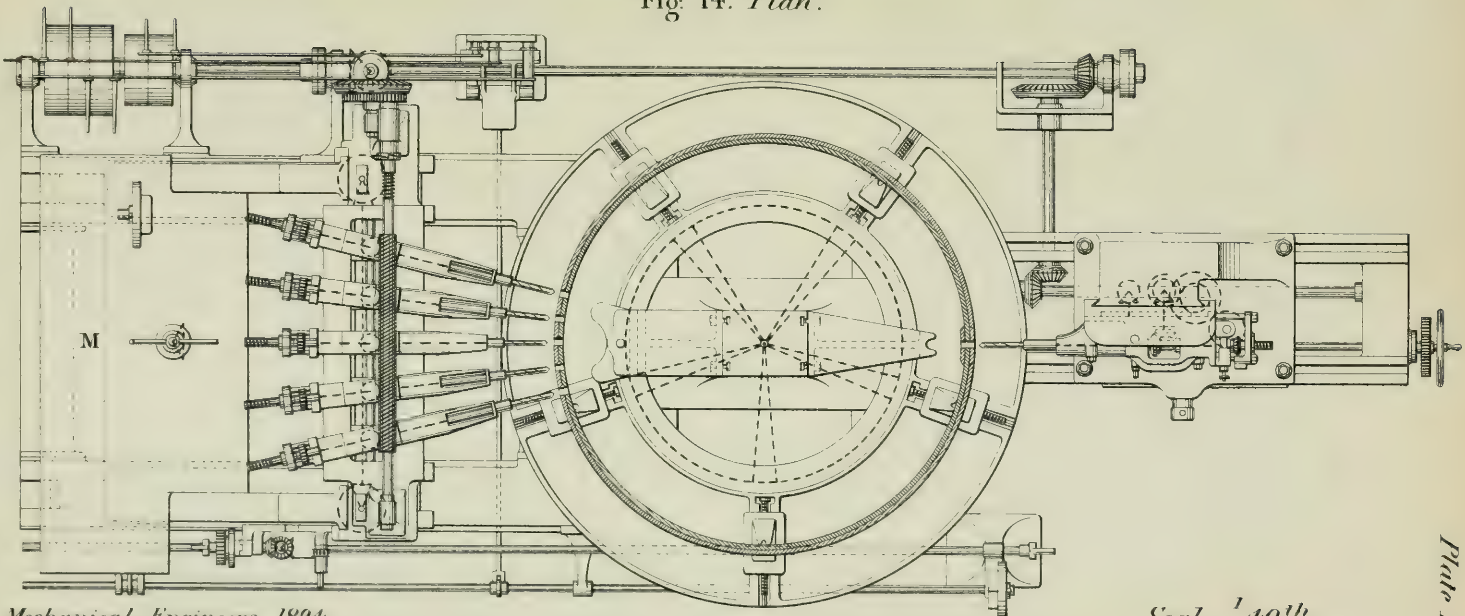
Inches 12 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 Feet

Plate 123.

BOILER-SHELL DRILLING MACHINES.

Multiple Drilling Machine.

Fig. 14. *Plan.*



Scale 1/40th

Inches 12 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 Feet

Plate 124.

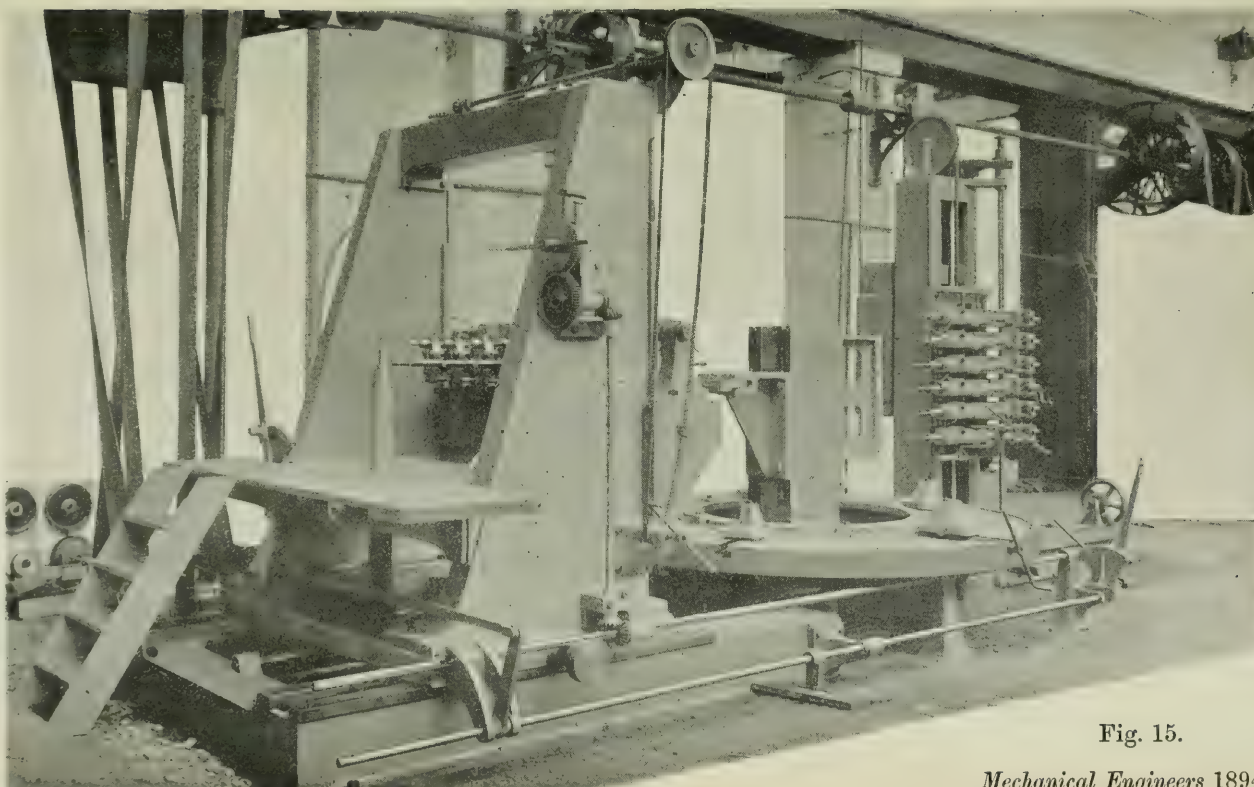


Fig. 15.

Plate 125.

BOILER-SHELL DRILLING MACHINES.

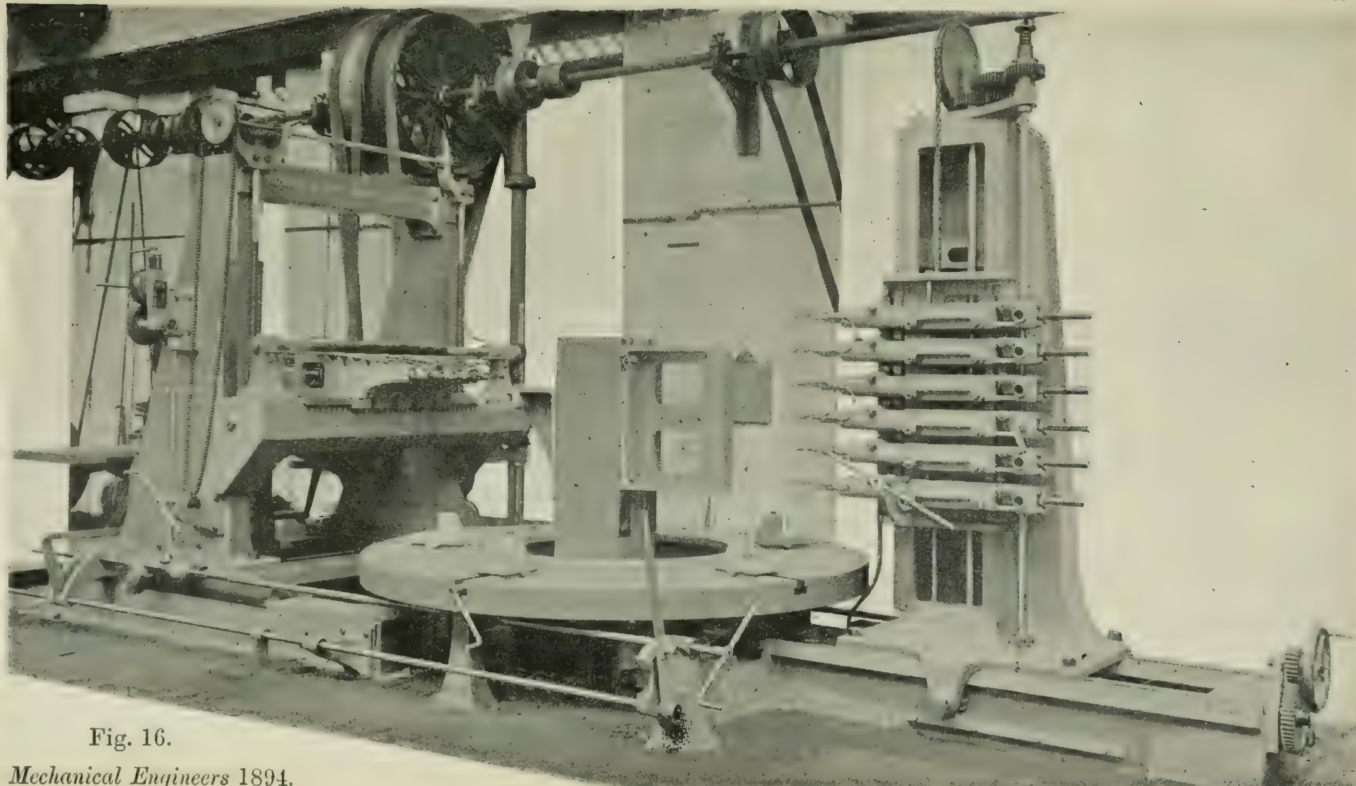


Fig. 16.

Mechanical Engineers 1894.

Plate 126.

BOILER-SHELL DRILLING MACHINES.

Radial Spindles, Suspended Shell.

Fig. 17.

End Elevation.

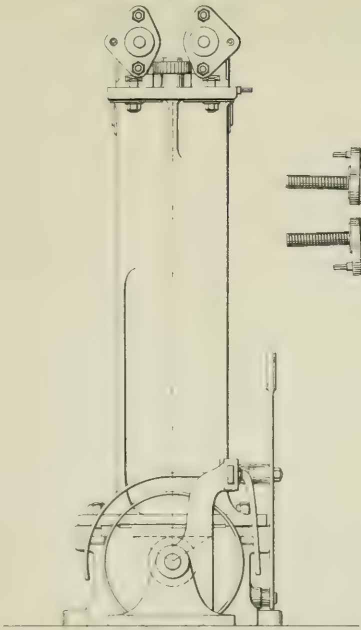


Fig. 18. *Plan.*

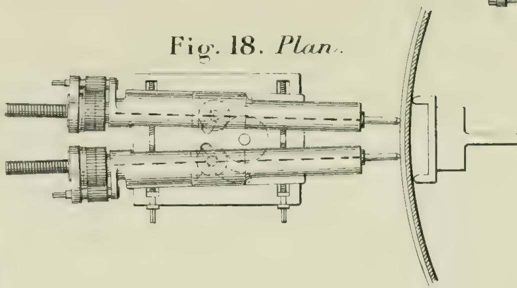
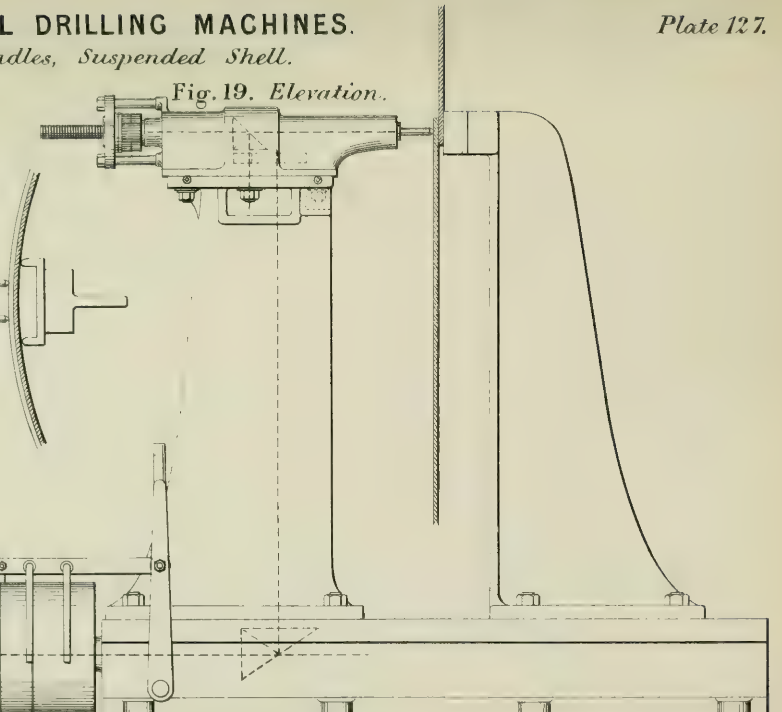


Fig. 19. *Elevation.*



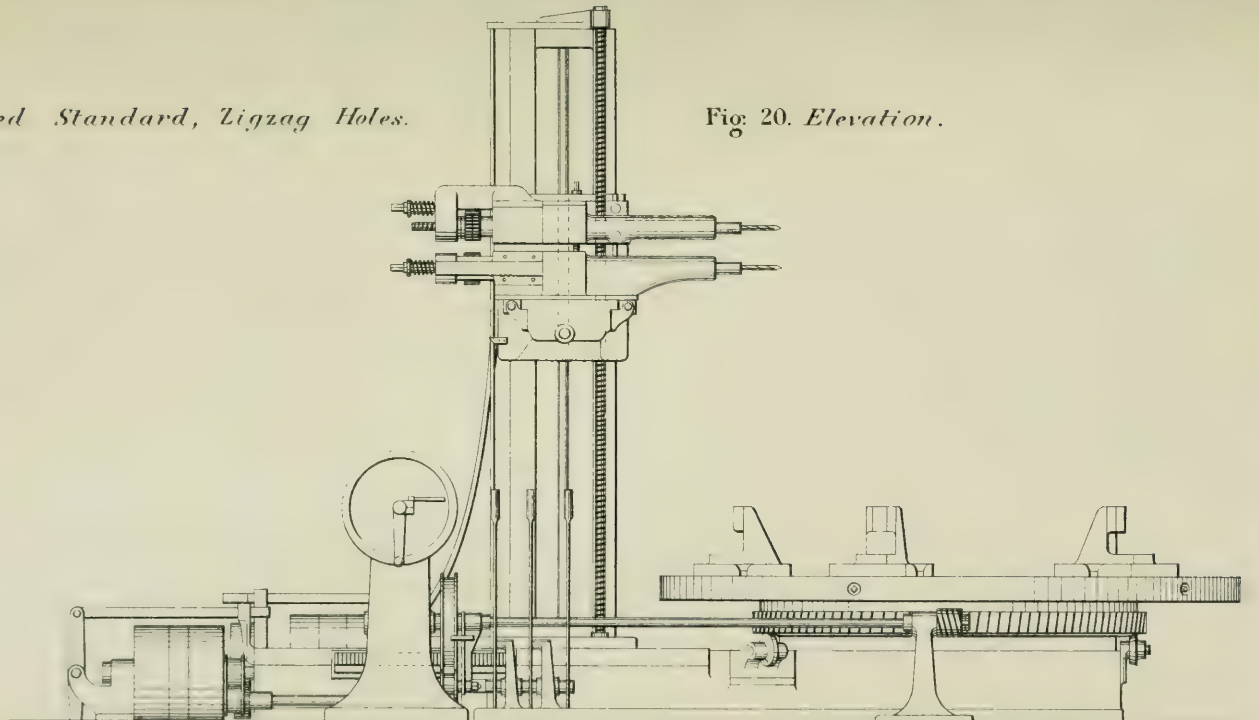
Scale $\frac{1}{24}$th.

Inches 12 6 0 1 2 3 4 5 6 7 8 Feet

BOILER-SHELL DRILLING MACHINES.

Fixed Standard, Zigzag Holes.

Fig. 20. *Elevation.*



Scale 1/32nd.

Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 *Feet*

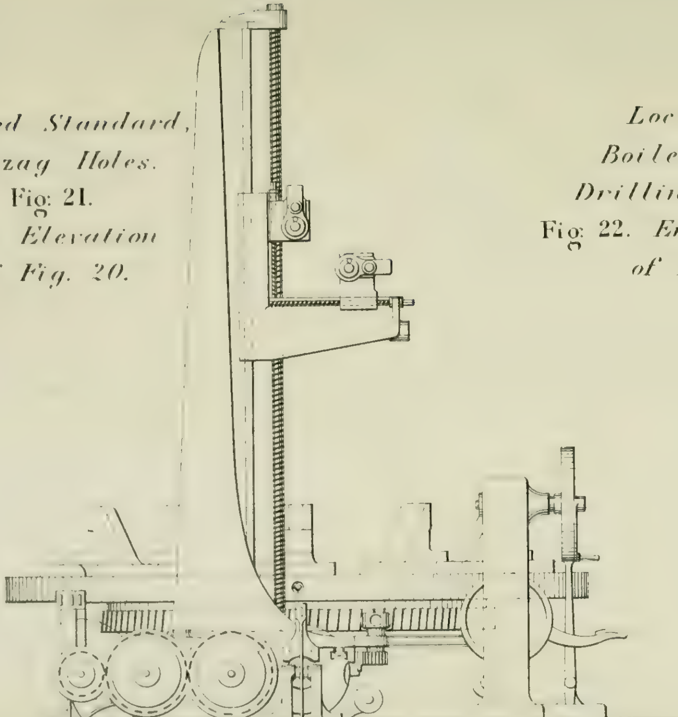
Plate 128.

BOILER-SHELL DRILLING MACHINES.

Fixed Standard, Zigzag Holes.

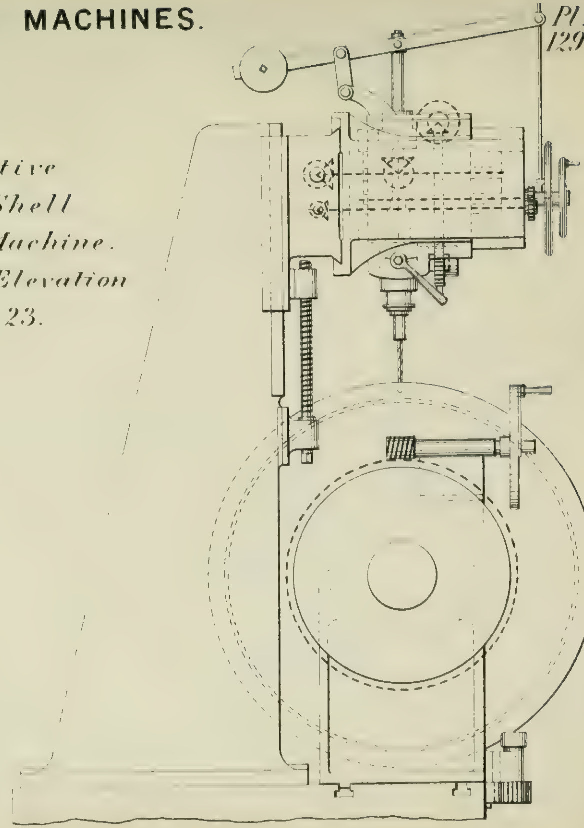
Fig: 21.

End Elevation of Fig. 20.



Locomotive Boiler-Shell Drilling Machine.

Fig: 22. *End Elevation of Fig. 23.*



Scale 1/32nd

Inches 12 6 0 1 2 3 4 5 6 7 8 9 Feet

Mechanical Engineers 1894.

BOILER-SHELL DRILLING MACHINES.

Locomotive Boiler-Shell Drilling Machine.

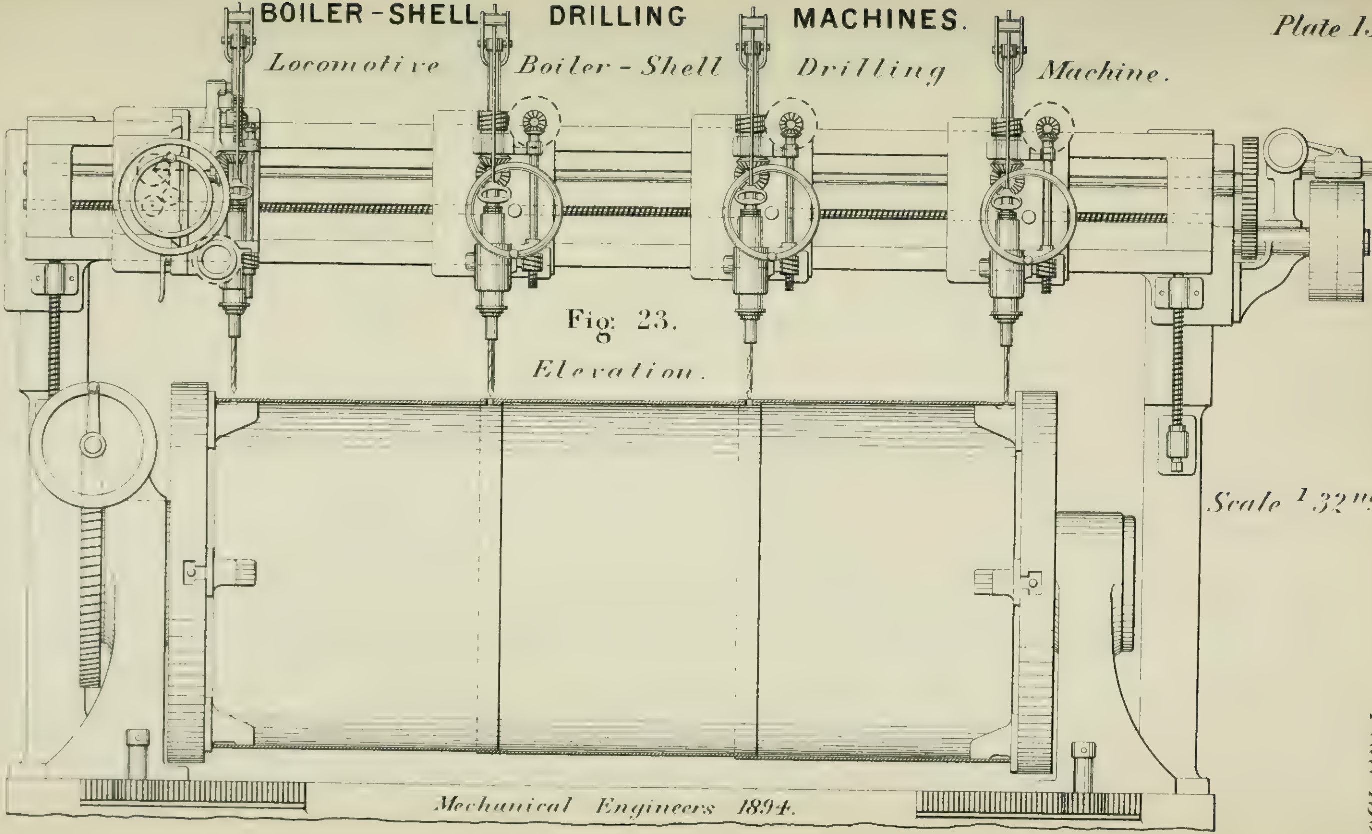


Fig: 23.
Elevation.

Mechanical Engineers 1894.

Plate 130.

BOILER-SHELL DRILLING MACHINES.

Plural Drilling Machine, for Locomotive Boilers.

Fig. 24. *End Elevation.*

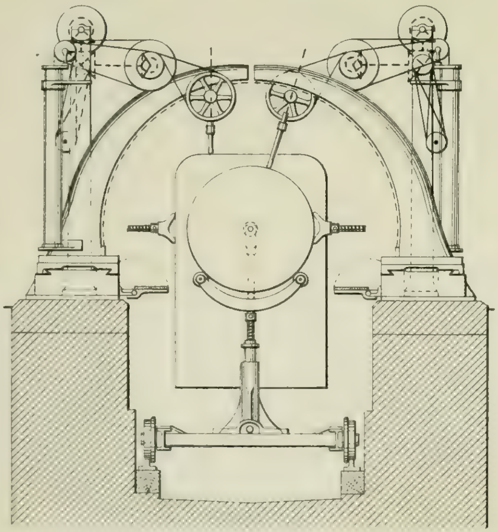
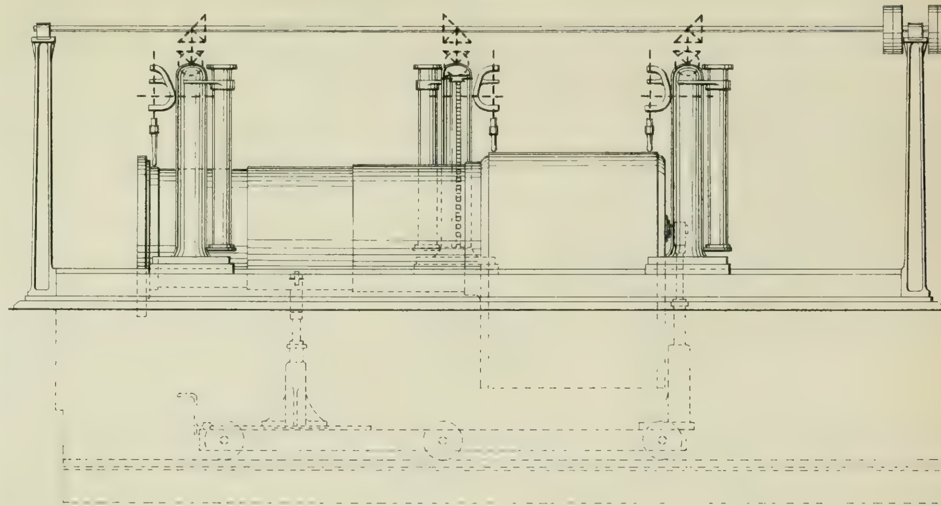


Fig. 25. *Elevation.*



Mechanical Engineers 1894.

Scale 1/72nd

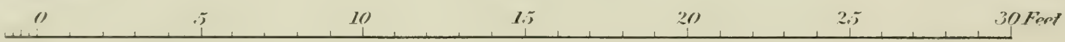


Plate 131.

BOILER-SHELL DRILLING MACHINES.

Plural Drilling Machine, for Locomotive Boilers.

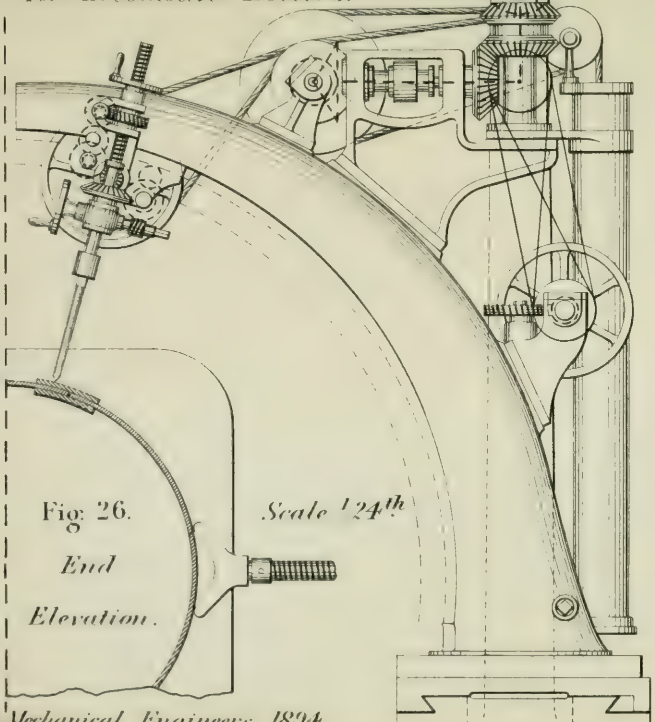


Fig: 26. *End Elevation.*

Scale 1/24th

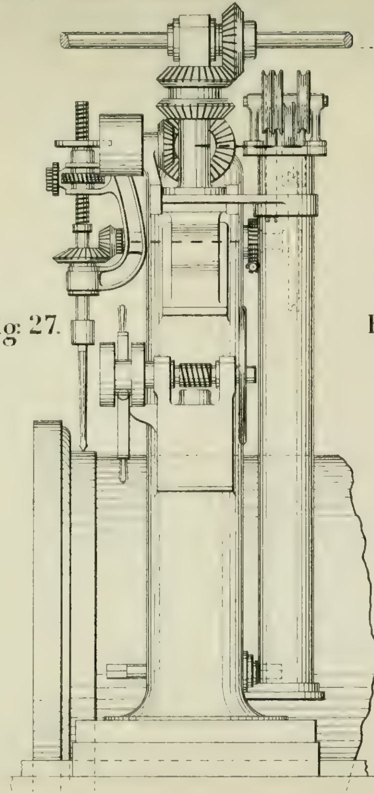


Fig: 27.

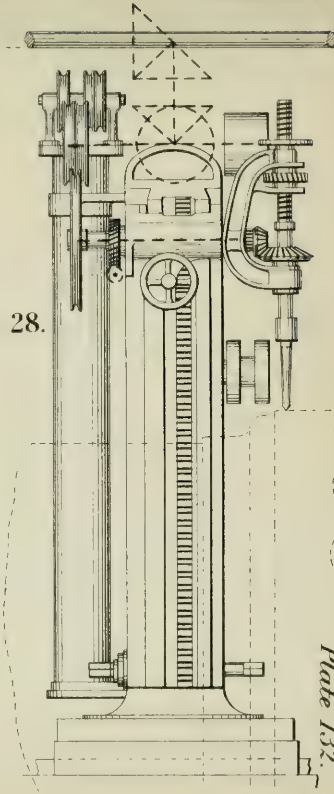


Fig: 28.

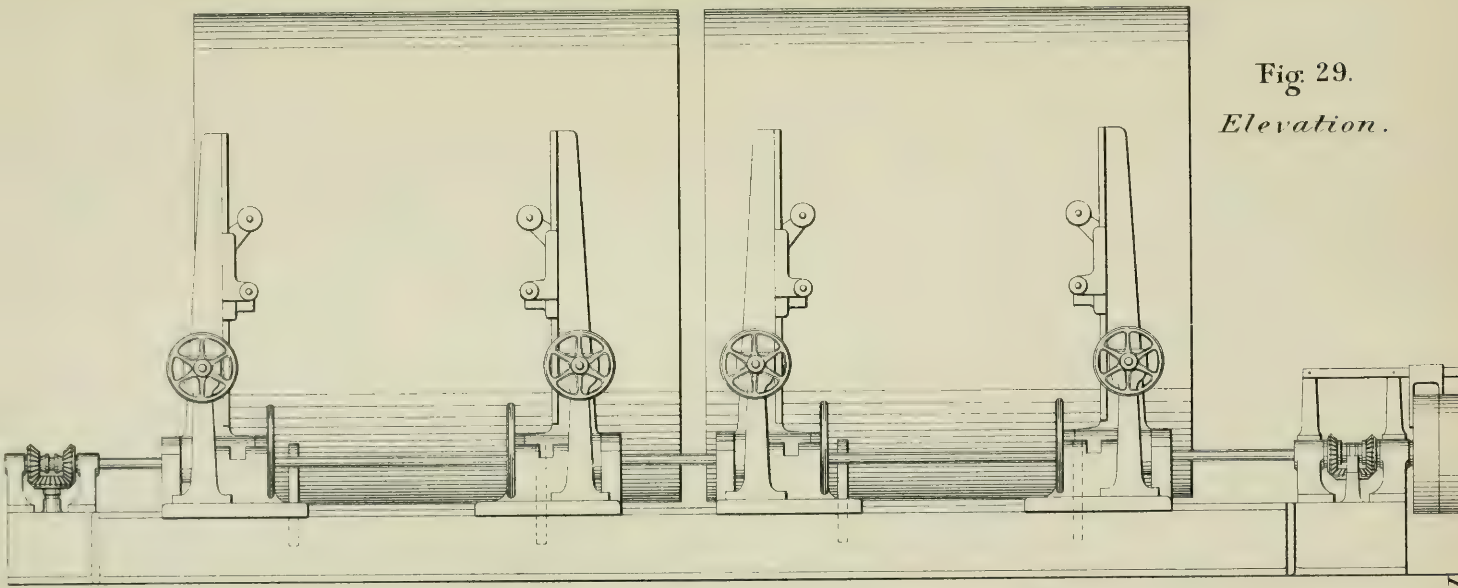
Plate 132.

BOILER-SHELL DRILLING MACHINES.

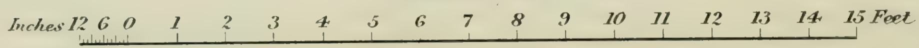
Horizontal Radial Drilling Machine, for Marine Boiler Shells.

Fig. 29.

Elevation.



Scale 1/48th.



BOILER-SHELL DRILLING MACHINES.

Horizontal Radial Drilling Machine, for Marine Boiler Shells.

Fig. 30.

Elevation.

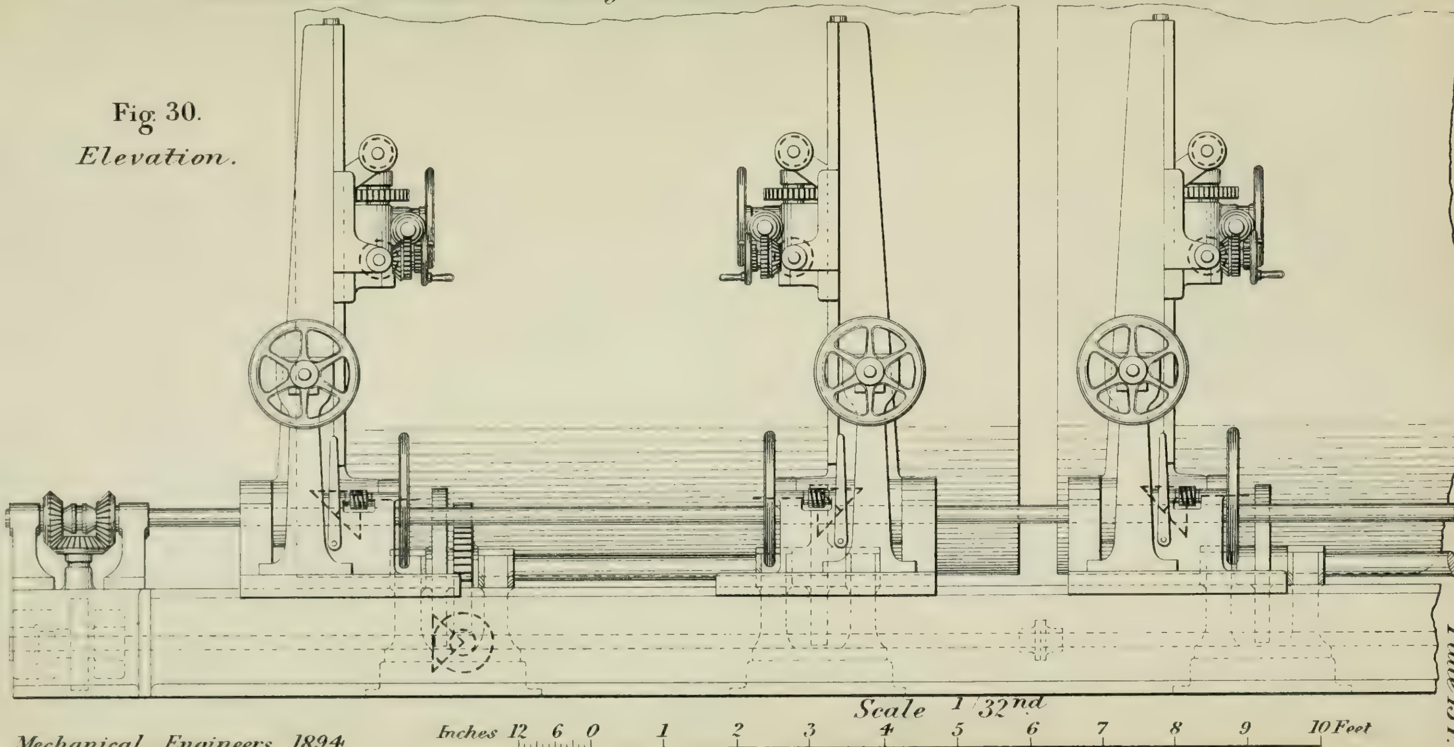


Plate 134.

BOILER-SHELL DRILLING MACHINES.

Horizontal Radial Drilling Machine, for Marine Boiler Shells.

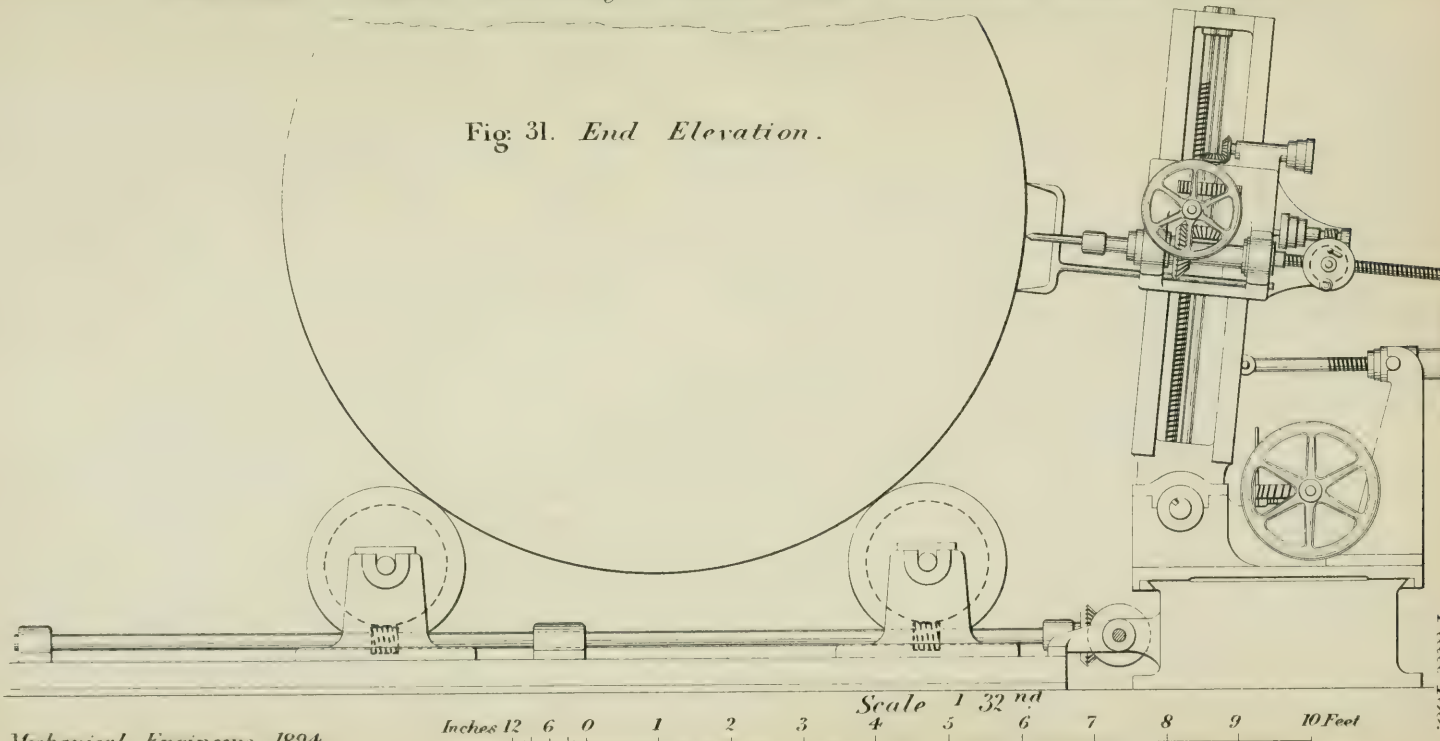


Fig. 31. *End Elevation.*

Plate 135.

Fig. 1. *Triple-Expansion Vertical Pumping Engine.*

Wapping.

Expt. 57.

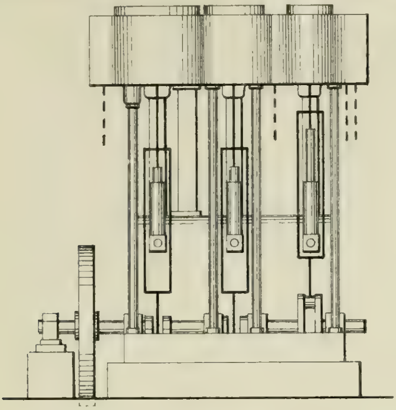
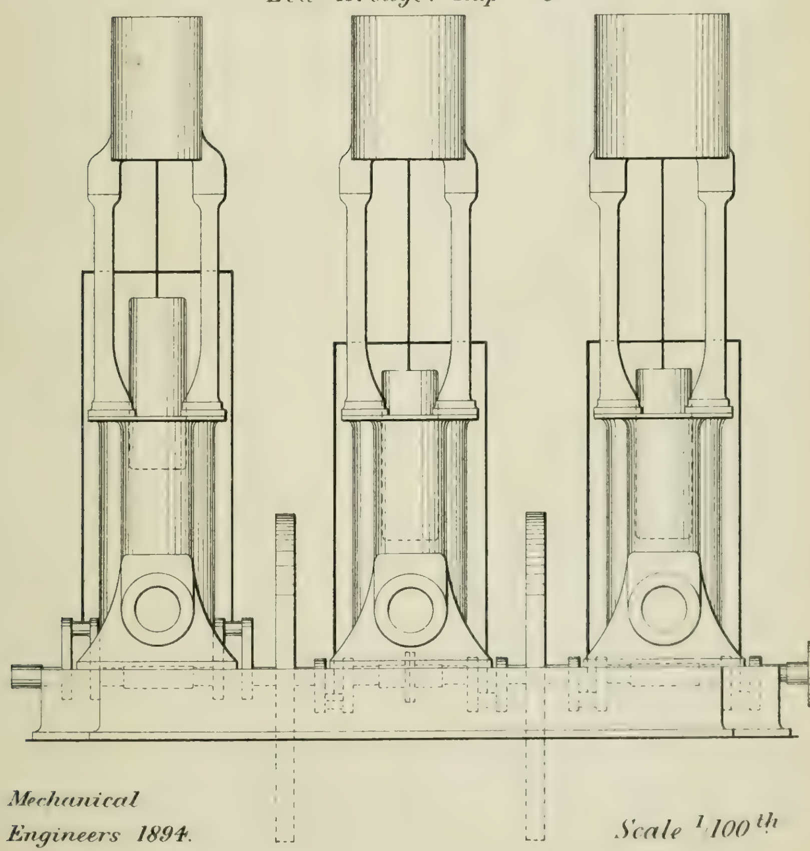


Fig. 2. *Triple-Expansion Vertical Pumping Engine.*
Lea Bridge. Expt. 58.



Mechanical Engineers 1894.

Scale 1/100th

Fig. 3. *Three-Cylinder Compound Vertical Pumping Engine. Blackfriars. Exp.^{t} 59.*

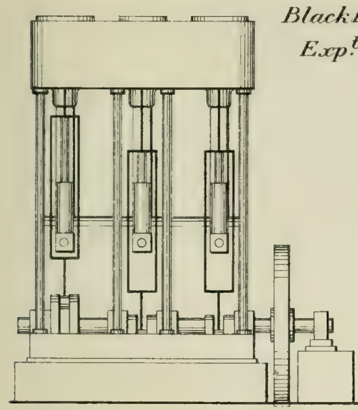
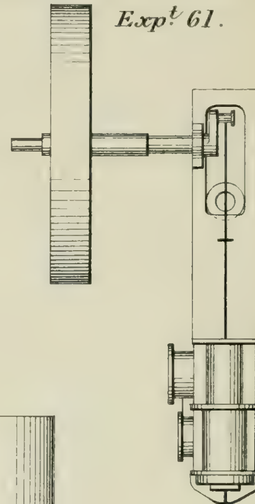


Fig. 5. *Compound Horizontal Engine. Gas Works, Vauxhall. Exp.^{t} 61.*



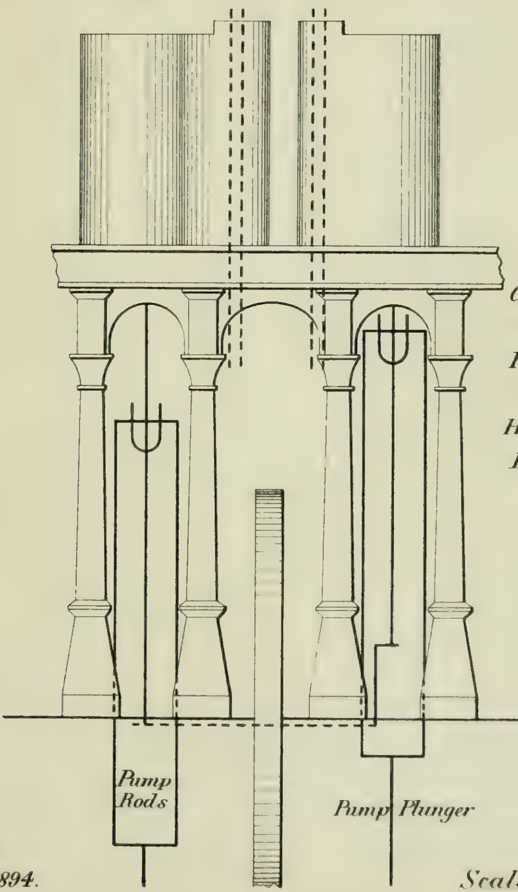


Fig. 4. *Compound Vertical Pumping Engine. Hampton. Exp.^{t} 60.*

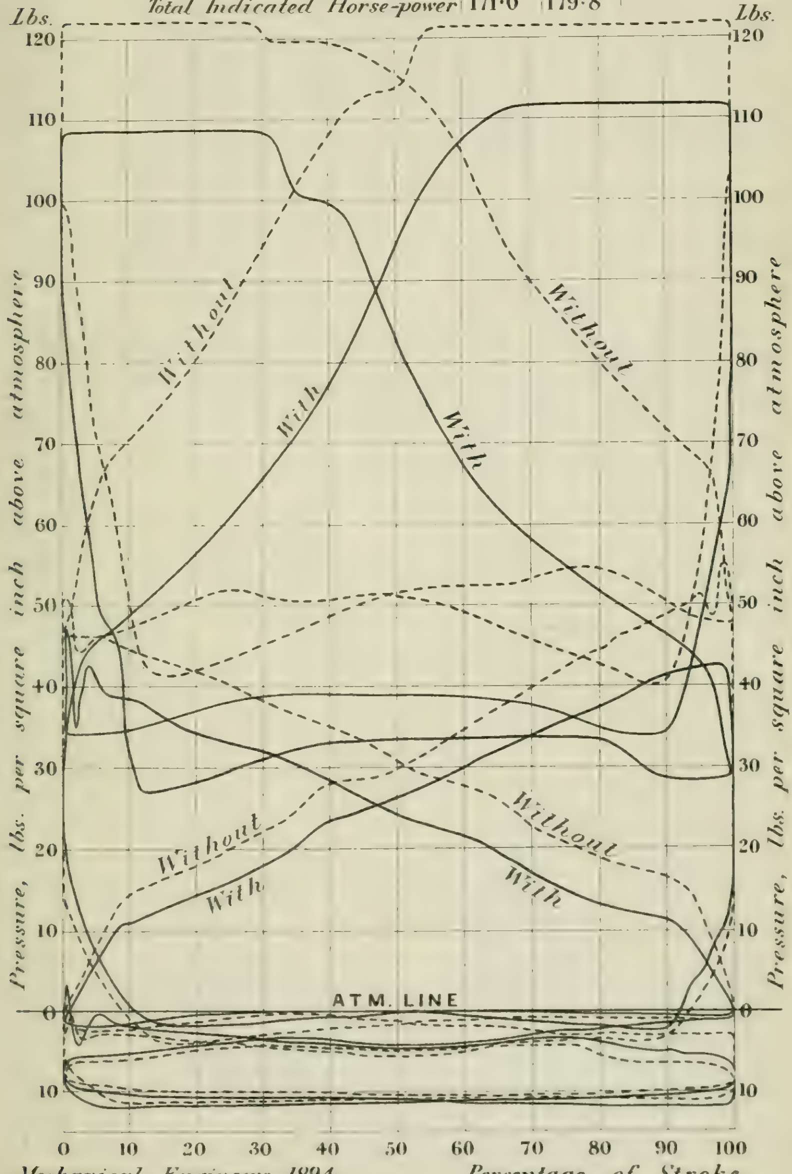
Scale 1/100th

VALUE OF STEAM-JACKET. *Plate 138.*

Triple-Expansion Vertical Pumping Engine. Wapping.

Fig. 6. *Indicator Diagrams nearest mean. Expt. 57.*

		d.	c
Trial Letter		d.	c
Jackets with or without steam		WITHOUT	WITH
Mean Effective Pressures (lbs. per sq. inch)	*High-p. cyl.*	52·59	46·39
	Inter. „	30·12	23·64
	Low-p. „	6·21	7·78
Revolutions per minute		52·74	59·76
Total Indicated Horse-power		171·0	179·8



Triple-Expansion Vertical Pumping Engine.
Wapping.
Expanded Indicator Diagrams nearest mean.
Experiment 57. Trials d *and* c.

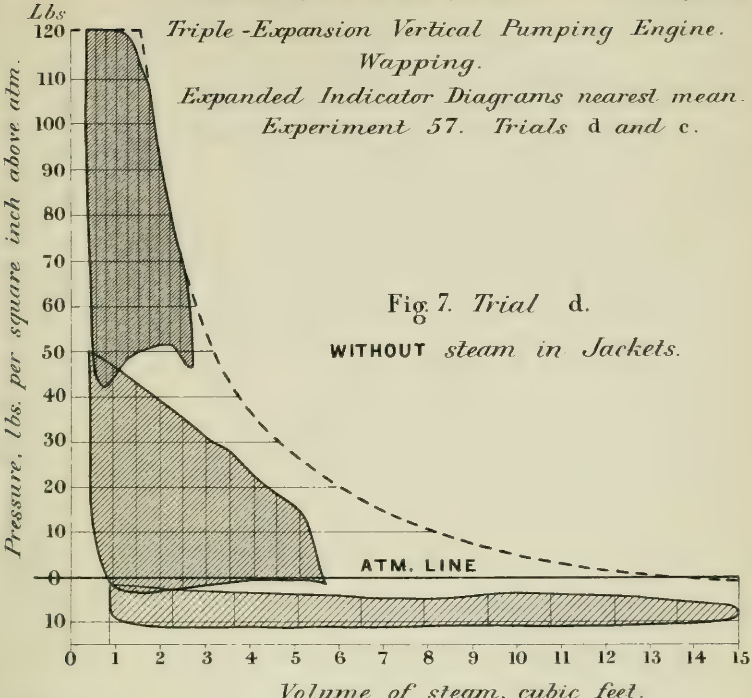


Fig. 7. *Trial* d.
WITHOUT *steam in Jackets.*

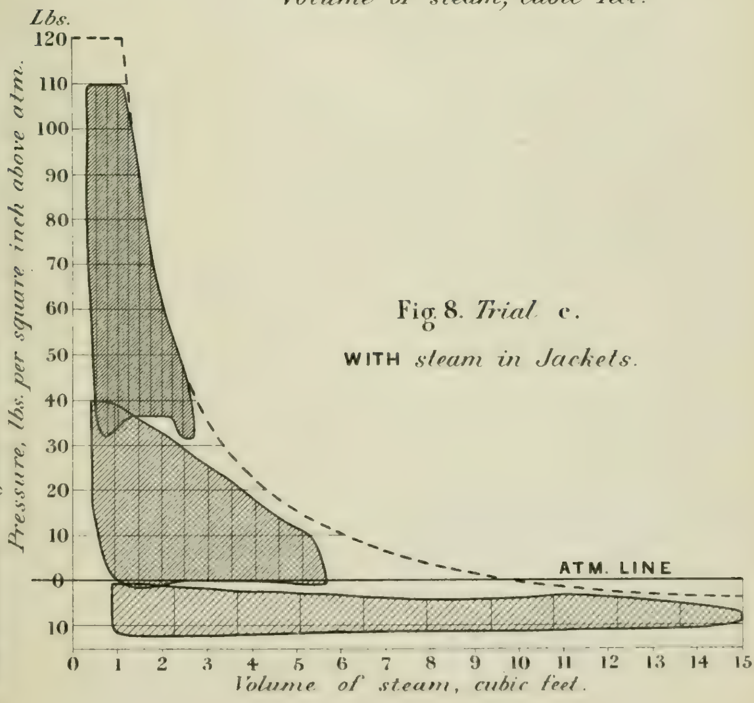


Fig. 8. *Trial* c.
WITH *steam in Jackets.*

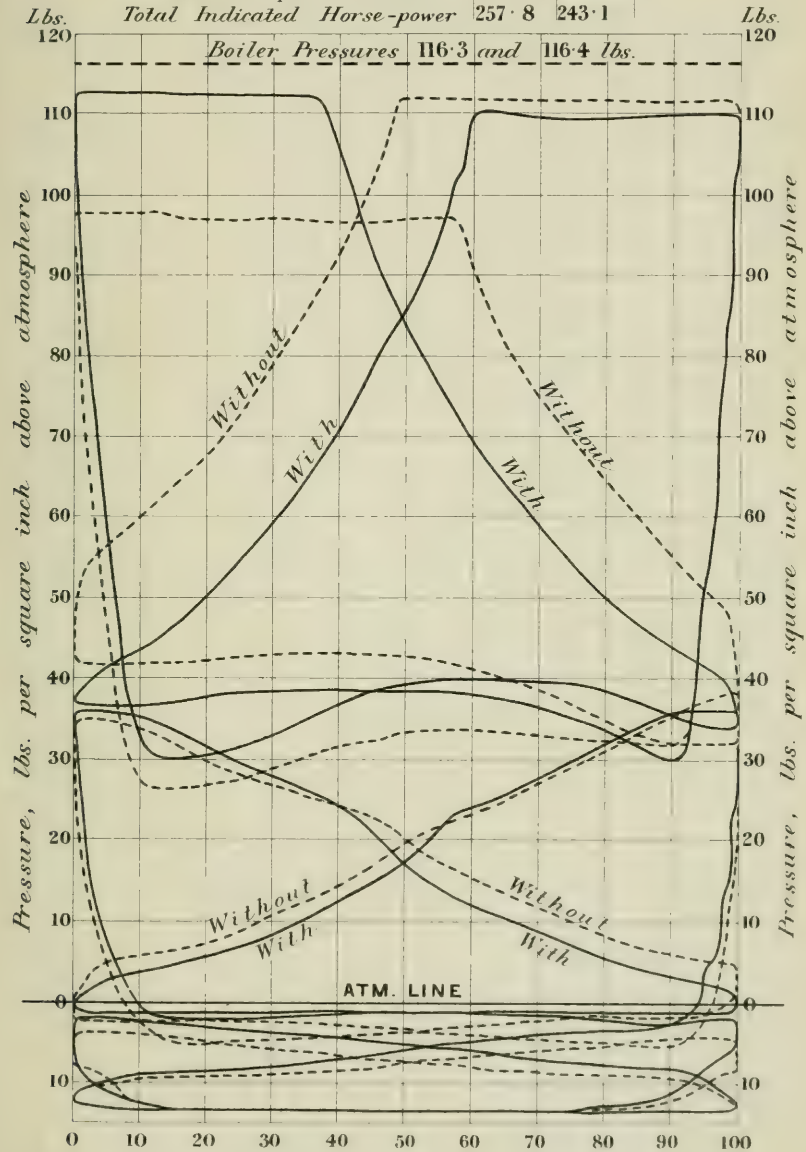
Mechanical Engineers 1894.

VALUE OF STEAM-JACKET.

Triple-Expansion Vertical Pumping Engine. Lea Bridge.

Fig. 9. *Indicator Diagrams nearest mean. North Engine. Exp[t] 58.*

		e	a	
Trial Letter		e	a	
Jackets with or without steam		WITHOUT	WITH	
Mean Effective Pressures	High-p. cyl.	50·42	43·35	lbs. per sq. inch
	Inter. "	21·76	19·45	
	Low-p. "	5·51	7·12	
Revolutions per minute		21·72	20·54	
Total Indicated Horse-power		257·8	243·1	



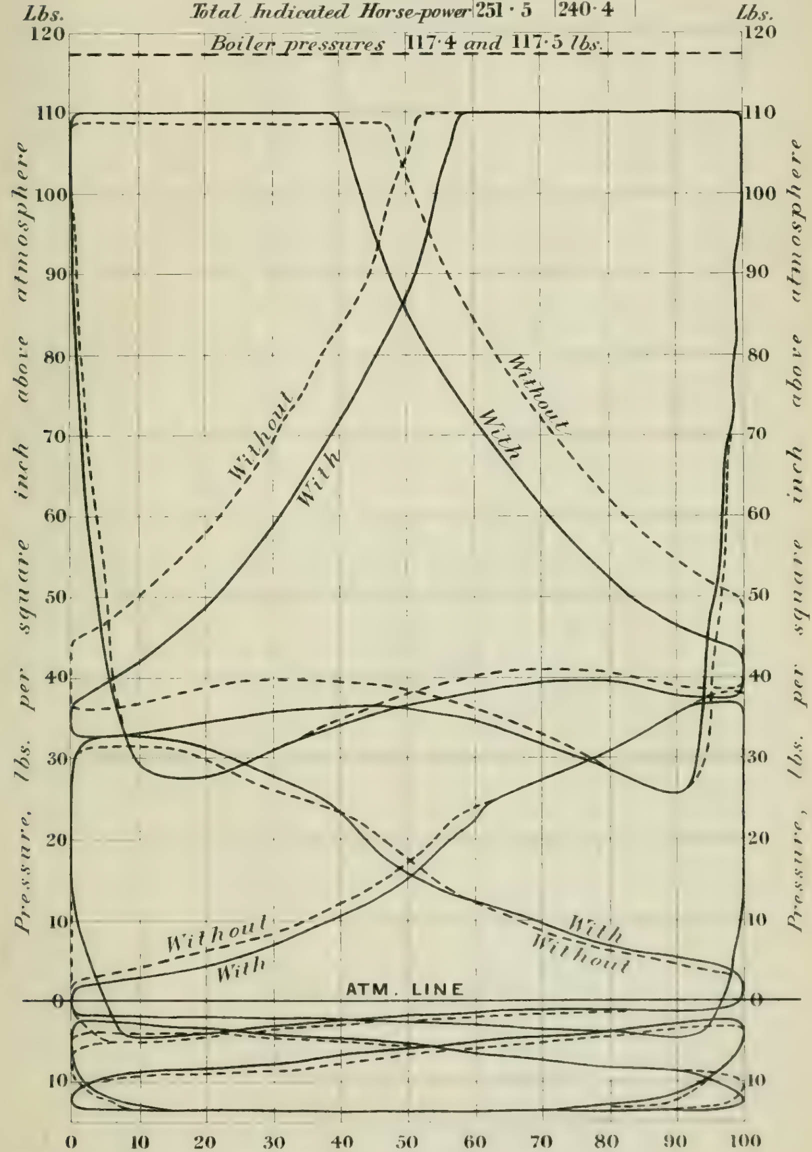
 Percentage of Stroke

VALUE OF STEAM-JACKET.

Triple-Expansion Vertical Pumping Engine. Lea Bridge.

Fig. 10. *Indicator Diagrams nearest mean. Central Engine. Expt. 58.*

		j	f	
Trial Letter		j	f	
Jackets with or without steam		WITHOUT	WITH	
Mean Effective Pressures	High-p. cyl.	51·21	46·50	lbs per sq. inch
	Inter "	20·32	19·32	lbs per sq. inch
	Low-p. "	6·09	6·86	lbs per sq. inch
Revolutions per minute		21·01	20·24	
Total Indicated Horse-power		251·5	240·4	



VALUE OF STEAM-JACKET. *Plate 142.*

Three-Cylinder Compound Vertical Pumping Engine. Blackfriars.
Indicator Diagrams nearest mean. Expt. 59.

Jackets with or without steam		WITHOUT	WITH	
Mean Effective Pressures	*High-p. cyl.*	51·59	44·90	*lbs. per sq. inch*
	Right Low-p.	11·45	14·94	
	Left Low-p.	12·81	15·42	
Revolutions per minute		47·83	47·84	
Total Indicated Horse-power		153·1	159·4	

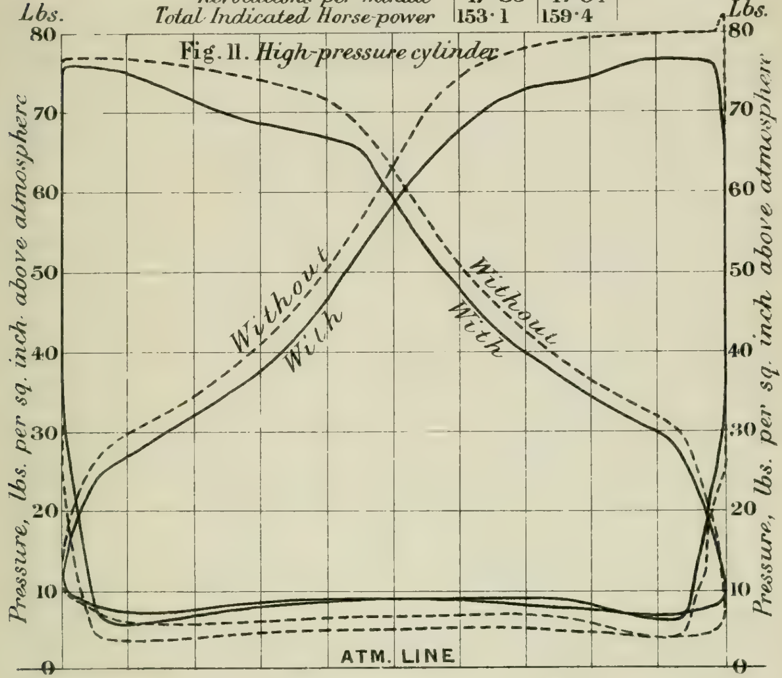


Fig. 11. *High-pressure cylinder.*

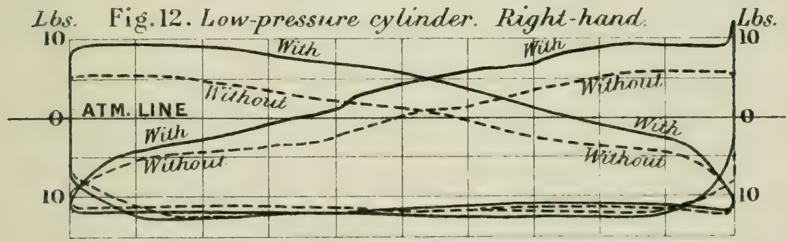


Fig. 12. *Low-pressure cylinder. Right-hand.*

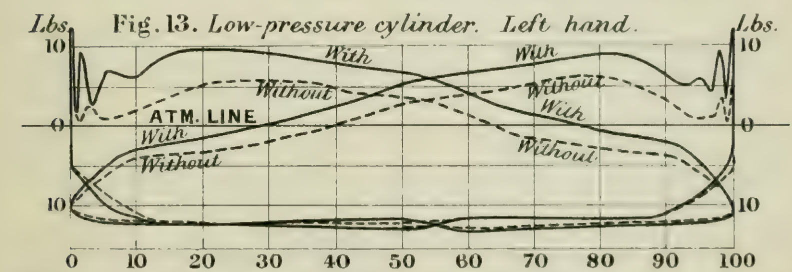


Fig. 13. *Low-pressure cylinder. Left hand.*

Mechanical Engineers 1894. *Percentage of Stroke*

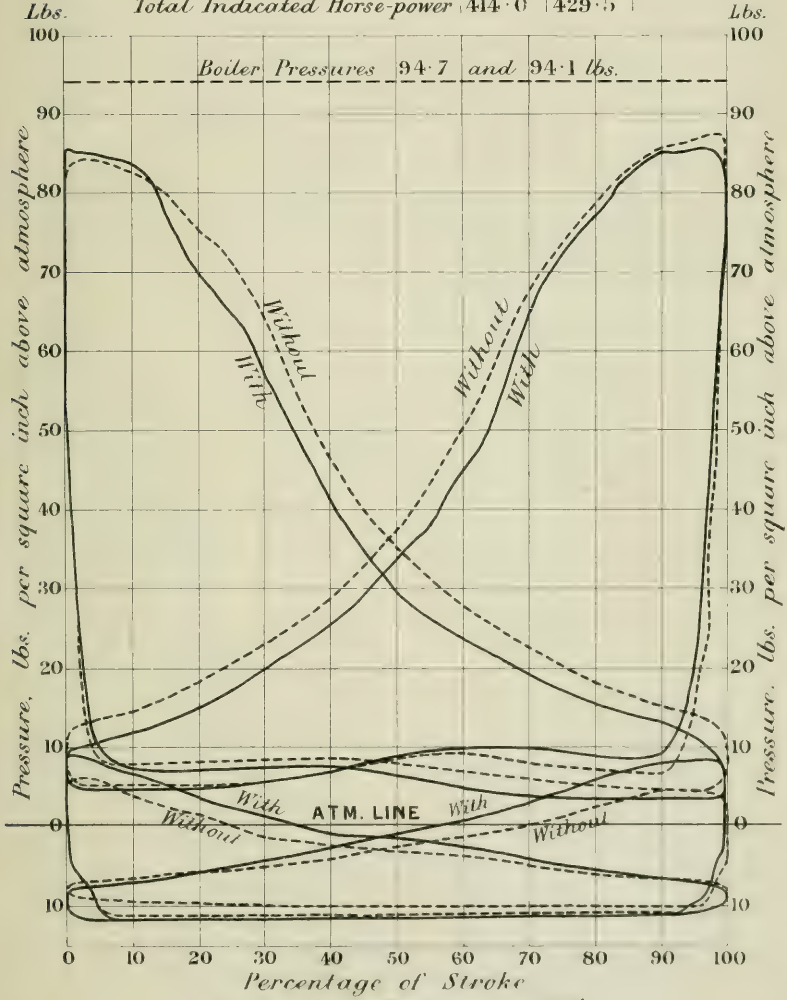
VALUE OF STEAM-JACKET. *Plate 143.*

Compound Vertical Pumping Engine. Hampton.

Fig. 14. *Indicator Diagrams nearest mean.*

Experiment 60.

Jackets with or without steam		WITHOUT	WITH	
Mean Effective Pressures	*High-p. cyl.*	35·81	32·16	*lbs. per sq. inch*
	Low-p. cyl.	8·19	10·31	*lbs. per sq. inch*
Revolutions per minute		21·22	21·23	
Total Indicated Horse-power		414·0	429·5	



VALUE OF STEAM-JACKET.

Compound Vertical Pumping Engine. Hampton.
Expanded Indicator Diagrams nearest mean.
Experiment 60.

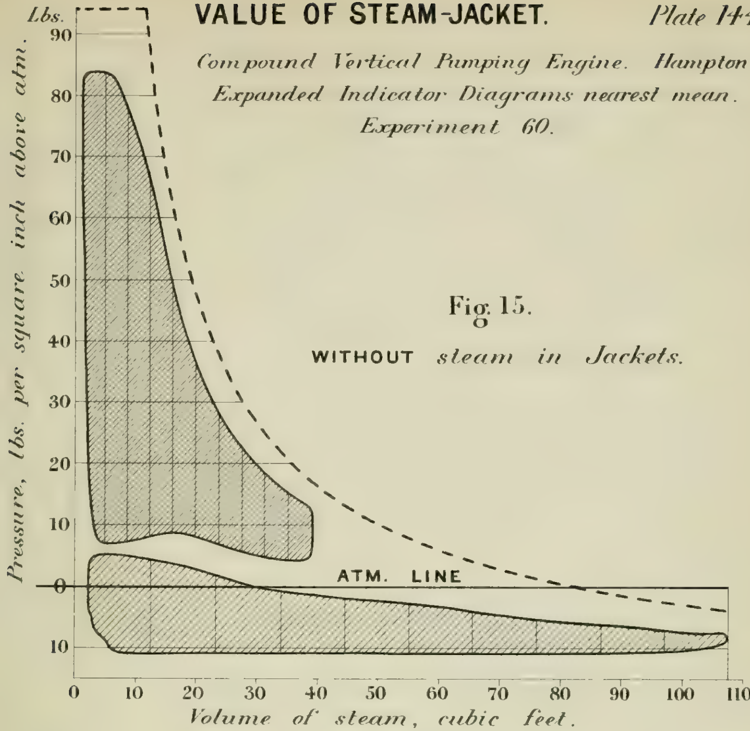


Fig. 15.

WITHOUT *steam in Jackets.*

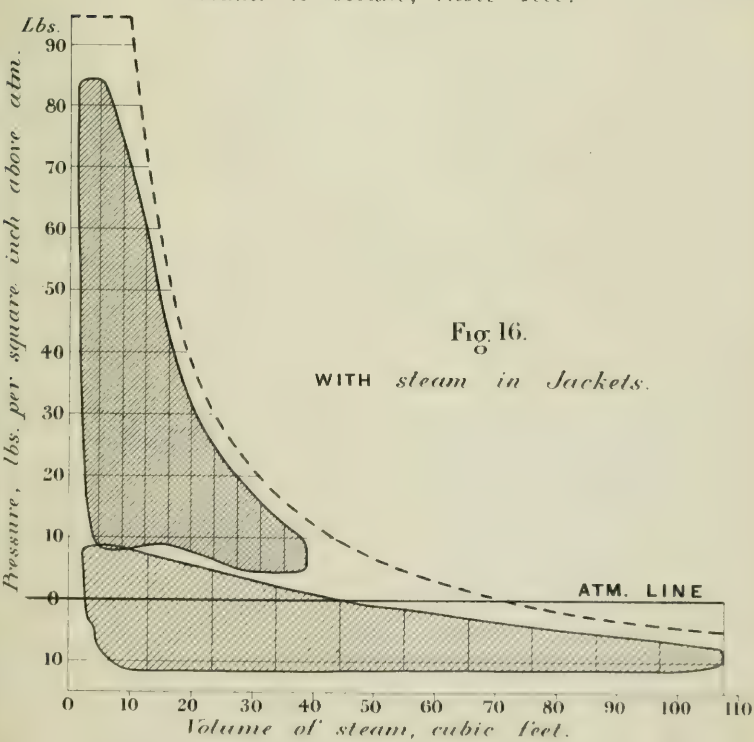


Fig. 16.

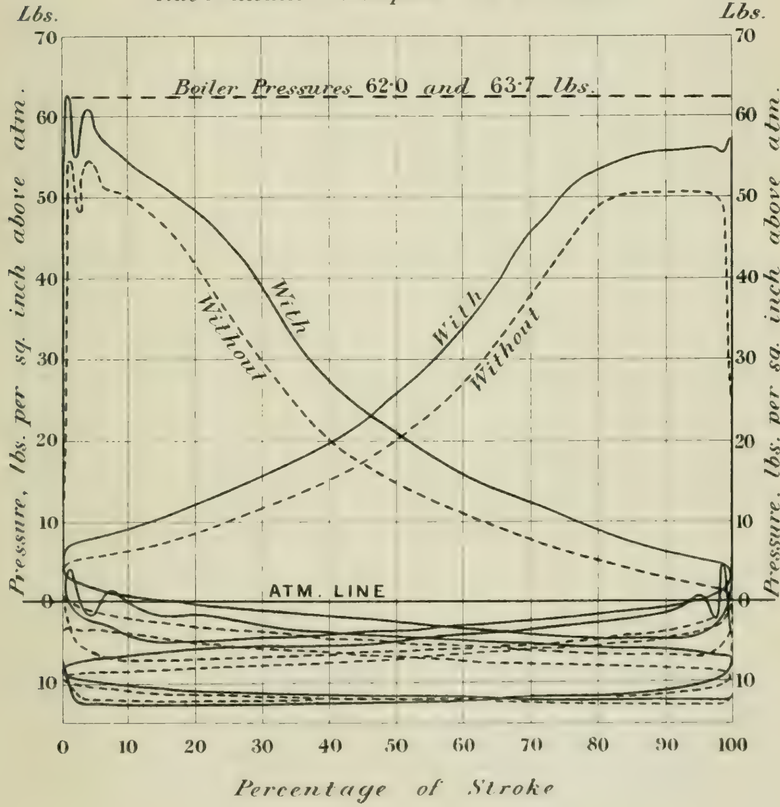
WITH *steam in Jackets.*

Compound Horizontal Engine. Gas Works. Vauxhall.

Fig. 17. *Indicator Diagrams nearest mean.*

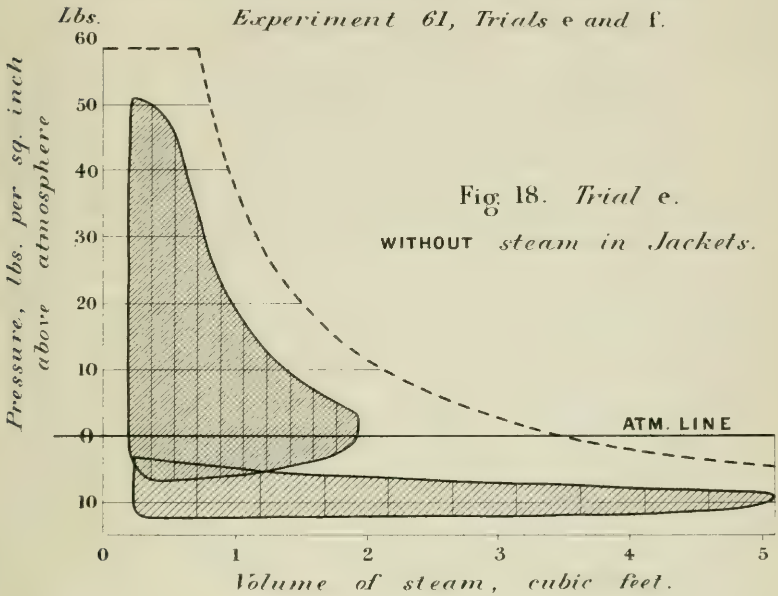
Experiment 61.

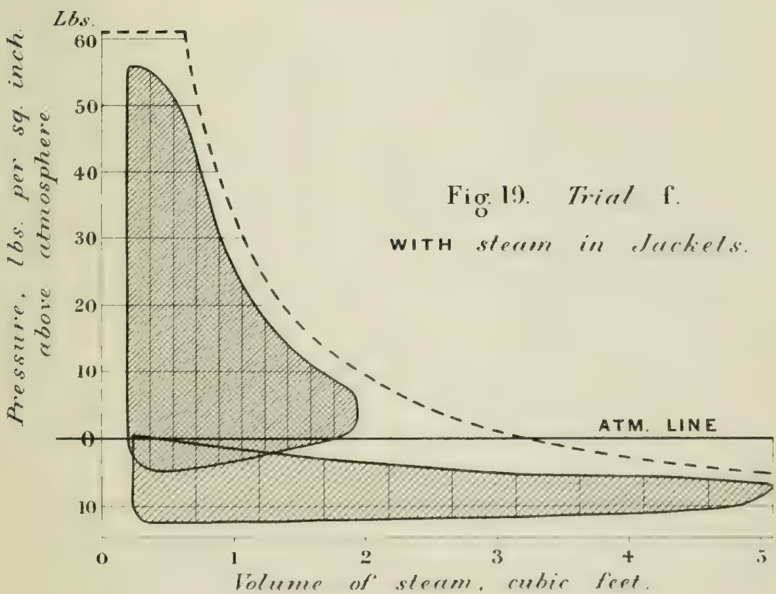
		e	f	
Trial Letter		e	f	
Jackets with or without steam		WITHOUT	WITH	
Mean Effective Pressures	*High-p. cyl.*	29·17	30·45	*lbs. per sq. inch*
	Low-p. "	5·894	7·597	*lbs. per sq. inch*
Revolutions per minute		79·67	79·88	
Total Indicated Horse-power		55·40	62·85	



VALUE OF STEAM-JACKET. *Plate 146.*

Compound Horizontal Engine. Gas Works, Vauxhall.
Expanded Indicator Diagrams nearest mean.
Experiment 61, Trials e and f.





VALUE OF STEAM-JACKET.

Triple-Expansion Vertical Pumping Engine. Wapping.

Fig. 20. *Dryness Fraction of Steam just before release. Experiment 57.*

N WITHOUT *Jacket.* J WITH *Jacket.*

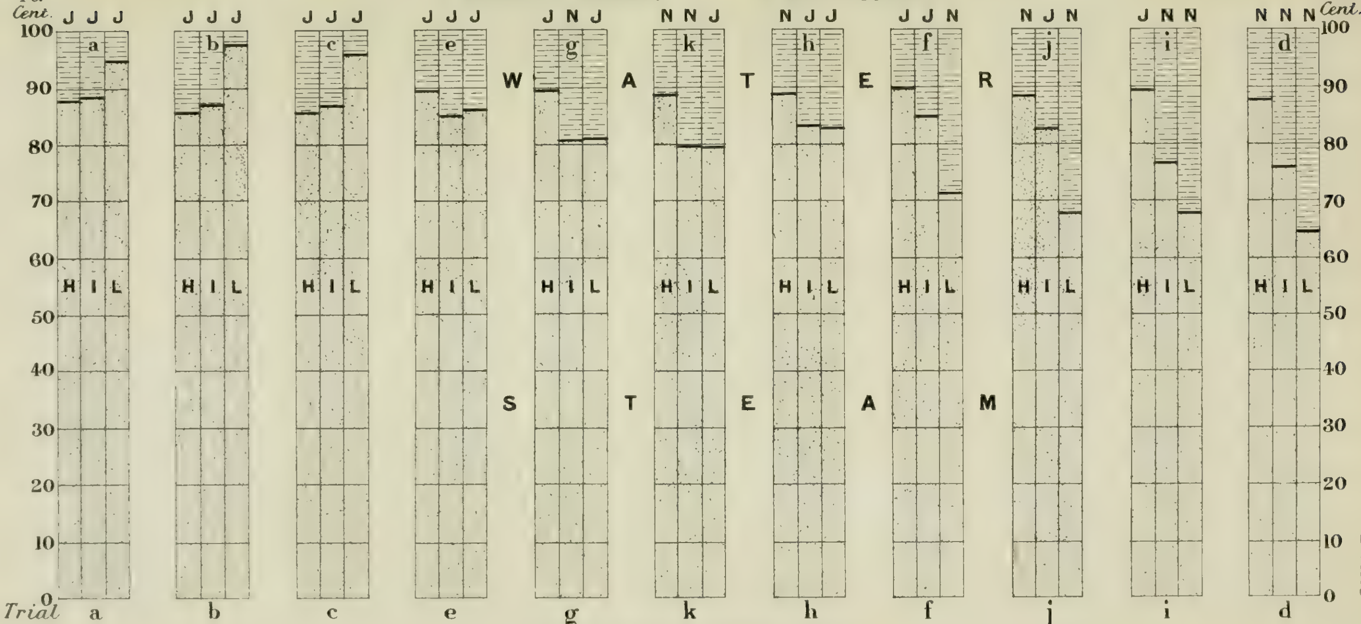


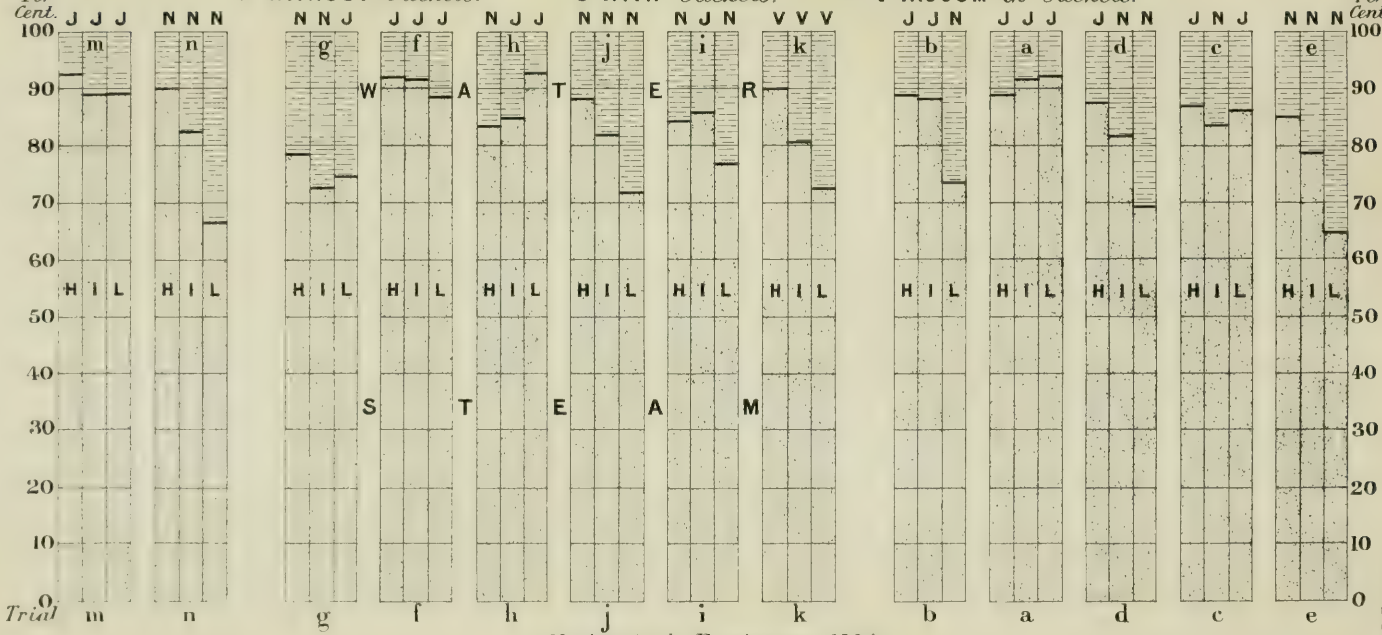
Plate 147.

VALUE OF STEAM-JACKET.

Triple-Expansion Vertical Pumping Engines. Lea Bridge.

Fig. 21. *Dryness Fraction of Steam just before release.* *Experiment 58.*

N WITHOUT *Jackets.* J WITH *Jackets.* V VACUUM *in Jackets.*



Mechanical Engineers 1894.

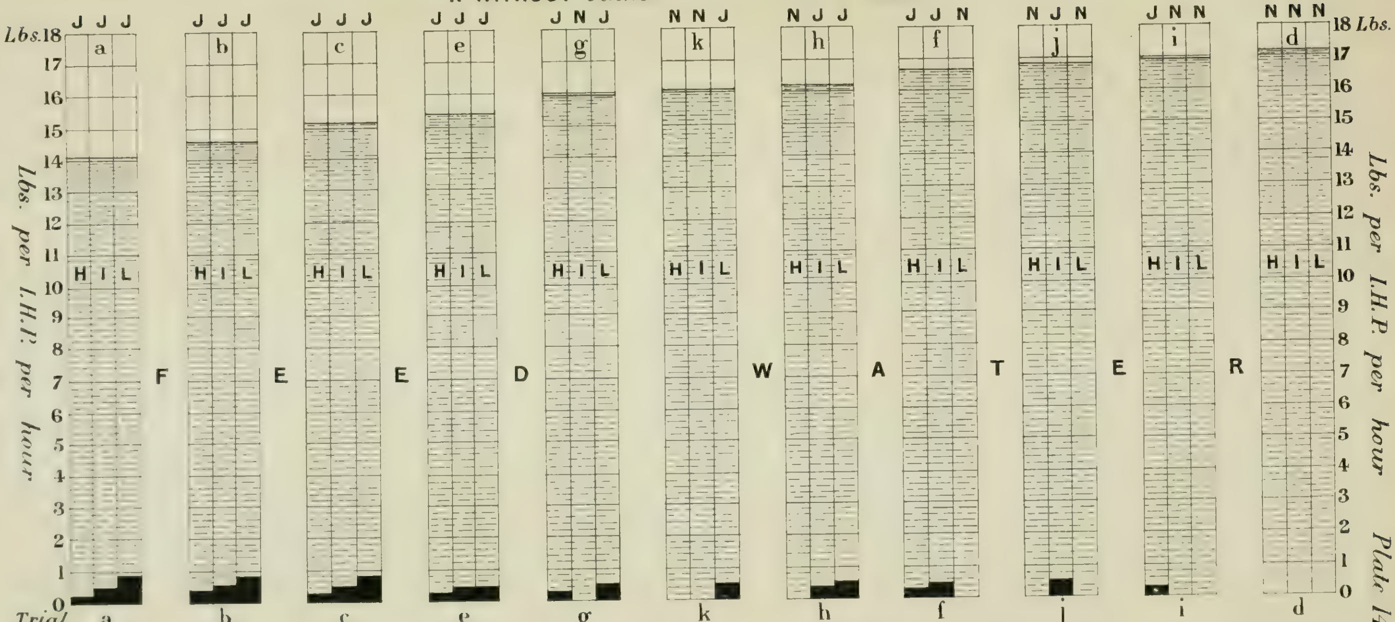
Plate 148.

VALUE OF STEAM-JACKET.

Triple-Expansion Vertical Pumping Engine. Wapping.

Fig. 22. *Total Feed-Water, including (black) Jacket-Water, per I.H.P. per hour.* *Expt. 57.*

N WITHOUT *Jacket.* J WITH *Jacket.*



Mechanical Engineers 1894.

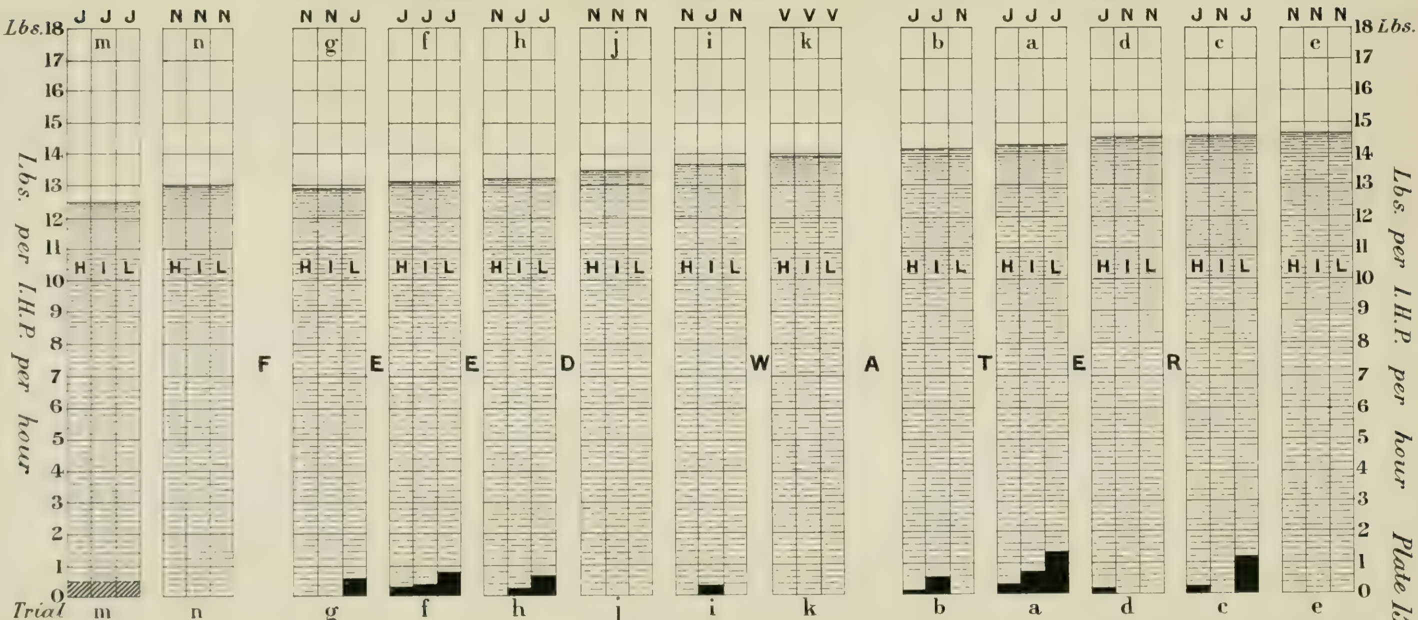
Plate 149.

VALUE OF STEAM-JACKET.

Triple-Expansion Vertical Pumping Engines. Lea Bridge.

Fig. 23. *Total Feed-Water, including (black) Jacket-Water, per I.H.P. per hour. Expt. 58.*

N WITHOUT *Jackets.* J WITH *Jackets.* V VACUUM *in Jackets.*



Mechanical Engineers 1894.